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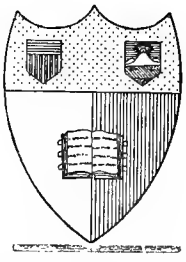

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BRITISH

PETROGRAPHY

WITH SPECIAL REFERENCE TO THE IGNEOUS ROCKS.

BY

J. J. HARRIS TEALL, M.A., F.G.S.

WITH FORTY-SEVEN PLATES.

LONDON:

DULAU & CO., 37, SOHO SQUARE.

1888.

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Ces agrégats vagues et inconstans, qu'on pourrait regarder comme *les incommensurables du règne minéral*, échappent à la méthode, qui n'a, pour ainsi dire, aucune prise sur eux, et qui ne peut les renfermer dans aucun des cadres destinés pour recevoir les véritables espèces. *Traité de Minéralogie, par M. l'abbé Haüy, 2nd Ed., Paris*, 1822, *T. IV., p.* 520.

Il y a cette grande différence entre les espèces géologiques et les espèces minéralogiques, que les principes des premières étant susceptibles de varier, soit dans leur arrangement, soit dans leur quantités respectives, admettent entre elles des successions de nuances et des passages gradués, au milieu desquel on a saisi certains termes assez éloignés entre eux, pour offrir des caractères propres à les faire contraster les uns à côté des autres. *Ibidem, p.* 529.

Bemrose & Sons, Printers, 23, Old Bailey, London, E.C.; and Derby.

PREFACE.

THIS work was commenced in February, 1886, and completed in March, 1888. One hundred and sixty-four pages and twenty plates were issued to subscribers in monthly parts. The issue then ceased, owing to the failure of the publishers, and I was compelled to take the work into my own hands in order to finish it.

It was my original intention to treat of the sedimentary rocks and crystalline schists in the same volume, but when I approached the consideration of these rocks I found that the space available was far too small for the purpose. I accordingly determined, notwithstanding the fact that several plates had been prepared, to postpone all detailed reference to these rocks, for the present, in the hope that I might be able to return to the subject on some future occasion. The plates that have been prepared are, however, issued with the present volume.

As regards the classification of rocks I am sorry to say that increasing knowledge has not tended to bring about any clearness of view. The more rocks are studied the less they seem to me to adapt themselves to any classification at all comparable in definiteness with the classifications of organic bodies and mineral substances. Rock-masses often vary so much in composition and structure that any scheme of classification based on work done in the laboratory is unsuitable for the expression of broad geological facts. It is absolutely impossible to map the different varieties recognized by modern petrographers. The conclusion at which I have arrived is that the necessity for giving names to rocks arises rather from work done in the field than from work done in the laboratory. Rock-specimens are mineral-aggregates and may be described as such. Rock-masses are integral portions of the earth's crust and possess a certain amount of individuality in virtue of their mode of occurrence.

It will be understood from these remarks that I attach very little importance to any of the rock-names used in the present work. My object has been to describe the structure and composition of the rocks; not to introduce new names or to add to the confusion already existing by giving new definitions of old names.

In the present state of petrographical nomenclature the student will be saved much trouble if he will fix his attention on the rocks themselves instead of on the names which have been used in different senses by different writers.

In carrying out my work I have received great assistance from many public institutions and private individuals. To the authorities of the British Museum I am greatly indebted for assistance in enabling me to examine the collections entrusted to their charge. The Allport collection is especially valuable and should be studied by all workers in British petrography. The Director General of the Geological Survey kindly allowed me to examine the large collection of slides of English rocks in the Museum of Practical Geology. Prof. JUDD has frequently assisted me, and I am indebted to him for the loan of slides from which several figures have been prepared. I have to thank Mr. ALLPORT for much kind help and for the loan of slides from his private collection. Prof. BONNEY, who was my tutor at Cambridge, and whose lectures were the means of inducing me to turn my attention to the science of geology, has always been ready with advice and similar assistance. Prof. HUGHES has aided me by the loan of sections from the Woodwardian Museum. I am also greatly indebted to many other friends, amongst whom I may mention: Mr. BARROW, Prof. BLAKE, Mr. DAVIES, Mr. DICK, Prof. HULL, Prof. LAPWORTH, Mr. MIERS, Mr. RUTLEY, Mr. WALLER and Mr. WORTH. To the gentlemen above-named, and to all those who have assisted me, I tender my warmest thanks.

Dr. HATCH has kindly furnished me with the Glossary which is printed after the text. He wishes me to state that it has been arranged with special reference to the structure, both macroscopic and microscopic, and mode of occurrence of rocks. Mineralogical terms frequently used in describing the constituents of rocks have been introduced, but rock-names have been rigidly excluded.

J. J. H. TEALL.

12, CUMBERLAND ROAD, KEW,

March 13th, 1888.

ABBREVIATIONS.

Q.J.G.S.	Quarterly Journal of the Geological Society. London.
G.M.	Geological Magazine.
M.M.	Mineralogical Magazine.
A.J.S.	American Journal of Science.
N.J.	Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.
Z.D.G.G.	Zeitschrift der deutschen geologischen Gesellschaft. Berlin.
P.A.	Poggendorf's Annalen für Physik und Chemie. Leipzig
J.G.R.	Jahrbuch der geologischen Reichsanstalt. Wein.
T.M.M.	Tschermak's Mineralogische und petrographische Mittheilungen. Wien.
Z.K.	Zeitschrift für Krystallographie. Leipzig.
A.M.	Annales des Mines. Paris.
B.S.M.	Bulletin de la Société Minéralogique de France. Paris.
B.S.G.	Bulletin de la Société Géologique de France.
C.R.	Comptes rendus hebdomadaires de l'Académie Française. Paris.
S.A.W.	Sitzungsberichte der K. K. Akademie der Wissenschaften. Wien.
S.A.B.	Sitzungsberichte der K. Akademie der Wissenschaften. Berlin.

CORRECTIONS.

Page 20. Last line, for *lencites* read *leucites.*

,, 36. For *elæolite* read *elæolite*, and for *Topax* read *Topaz.*

,, 38. Foot-note (3), for 185 read 1865.

,, 43. Line 27 for *effects* read *effect.*

,, 58. Line 8 for (2) read (1); and line 32 for (1) read (2).

,, 82. Line 23 for *Schreisheim* read *Schriesheim.*

,, 95. Line 9 for *former* read *latter* and for *latter* read *former.*

,, 114. Line 30 after p. insert 109.

,, 124. Line 27 for VI. read V.

,, 144. Line 14 for NaO read Na^2O.

,, 156. Line 31 for Houghton read Haughton.

,, 157. Line 28 for $11\bar{1}$ read $\bar{1}11$, and line 30 for $11\bar{1}$ read $\bar{1}11$.

,, 163. Line 31 for *orthopinacoid* read *macropinacoid.*

,, 218. Line 4 for *Cwlyd* read *Cawlyd.*

,, 222. Line 41 for DAVIS read DAVIES(3).

,, 231. Line 45 for (011) read (110).

,, 246. Line 9 for HARDMANN read HARDMAN.

,, 270. Foot-note (2) for VALLÉE-POUSSEN read VALLÉE-POUSSIN.

,, 272. Line 2 for *to* read *of*, and line 38 for TiO read TiO_2.

,, 303. Line 2 for Ballygohen read Ballygihen; line 4 for Roueval read Roneval; line 23 for $(\gamma - \alpha)$ read *difference between greatest and least refractive indices.*

Plate XIII. Fig. 1. The colour of the augite is a pale violet, not a brilliant pink as represented.

Plate XVI. Fig. 2. The fresh olivine substance in this rock is nearly colourless, not as represented.

Key Plate XLVII. for FIG. 4 read FIG. 5 and for FIG. 5 read FIG. 4.

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INTRODUCTION.

THE rocks of which the earth is composed, or which fall on the earth's surface from outside space form the subject matter of petrography. It is extremely difficult to frame any definition of the term rock, to which exception may not be taken. In its widest sense it may be said, without risk of serious error, to include every solid mass [1] of considerable size which forms an integral portion of the earth or of some other cosmic body, and which cannot be referred to one crystalline or organic individual. As a general rule rocks are aggregates, composed of individual substances which owe their solid form either to crystalline or organic activity. In the present work we shall limit our attention, for the most part, to those masses which are important as constituent portions of the earth's crust, and which show, therefore, a considerable amount of uniformity when traced over extensive areas. Meteorites or extra-terrestrial rocks, and the contents of mineral veins, lodes and drusy cavities will not be referred to at any length.

At the outset it is necessary to remark that petrography is a branch of geology, and not merely a department of mineralogy. Rocks are, it is true, for the most part mineral aggregates, and much of the work of the petrographer is therefore of a mineralogical character. His principal attention, however, is directed not to the study of the rock-forming minerals as individuals, but to their mutual relations in the rocks themselves, and to the behaviour of the rock masses as constituent portions of the earth's crust. The minerals, quartz and felspar, occur as constituents of a variety of granite, and also of arkose, a rock resulting from the disintegration of granite, and the deposition of the constituents under the influence of surface agencies. A petrographical classification, based on mineralogical composition alone, would therefore place granite and arkose in the same group, and thus ignore a most important and well established fact in the history of the latter rock.

The above illustration serves to emphasise another most important fact with reference to the science of petrography. Rocks may be studied from two more or less distinct points of view—the descriptive and the aetiological. We may set to work to describe them—to ascertain and record every possible fact with regard to their composition, structure and mode of occurrence—or we may endeavour to trace the succession of events which has culminated in the state of things we actually observe. Descriptive petrography deals with :—

(1) The physical and chemical characters of the rock as a whole.
(2) Its mineralogical composition.
(3) The forms and mutual relations of the constituent parts.

(1) The expression "solid mass" must not be interpreted too literally. Interspaces frequently occur between the constituent parts of certain rocks, and gas and fluid cavities are often found in the individual minerals of which rocks are composed. Again, the term rock is also applied to loosely coherent masses of gravel, sand and clay.

(4) The structures and mutual relations of the rock masses.

(5) The distribution of the different rock-types in space and time.

As the present work will be devoted mainly to descriptive petrography, in so far as this is dependent on the examination of hand specimens,[1] it will be impossible to enter at length into the discussion of general questions relating to the origin of rocks; at the same time it will be equally impossible to avoid all reference to such questions in consequence of their bearing on petrographical classification.

In considering the history of a rock it is necessary to bear in mind that two more or less distinct questions are involved: (1) the origin of the minerals of which the rock is composed, and (2) the origin of the rock itself. In some cases there is the most intimate connection between the origin of the rock and that of the minerals which enter into its composition: thus igneous rocks have, for the most part, been formed by the successive crystallisation of the constituent minerals from a molten magma. The minerals have been developed *in situ*—they are *authigenic*.[2] In other cases, as for instance amongst the sedimentary rocks, the origin of the minerals is for the most part wholly distinct from that of the rock; they have not been developed *in situ*—they are *allothigenic*.[3]

Molecules are the units of the mineralogist; minerals are the units of the petrographer. Minerals are definite chemical compounds; the laws which determine their formation are those of chemistry; the molecules of which they are composed are brought together by the force of chemical attraction. Rocks are for the most part mineral aggregates; the laws which determine their formation are those of physics; the minerals of which they are composed are brought together in various ways, but always under the influence, and often by the direct operation of the force of gravity.[4]

Consider now the causes by which rocks are known to be produced and modified. In dealing with this subject a slight confusion arises in consequence of the impossibility of separating by any hard and fast line the rock-producing from the rock-modifying agents. The production of a rock is not the result of one act, but of a long series of changes, and it must therefore be remembered that if we regard any one of these changes as giving individuality to the rock—as marking so to speak its birth—this is done merely for the sake of convenience, and not for the purpose of limiting enquiry. It is impossible to define with precision the moment in the history of a rock at which it acquires individuality. A convenient classification, however, will be seen to arise out of the following considerations.

The rocks which form the surface of the earth are in contact with air and water, and subject to various chemical and physical agents of change

(1) This branch of the subject is frequently termed lithology.

(2) Authigenic, from *αὐθι, on the spot, here.*

(3) Allothigenic, from *ἀλλοθι, elsewhere, in another place.*

(4) See Lossen. Ueber die anforderungen der Geologie an die petrographische Systematik. Jahr. d. geol. Landesanstalt, Berlin, 1884.

which depend on surface conditions, and which may therefore be conveniently referred to as the surface agencies. The extent of alteration produced by these agencies varies from nothing to the complete disintegration of the rocks, and the breaking-up of their constituent minerals into chemical compounds which are more stable under the existing conditions. Under the influence of these agencies the materials of certain rocks are removed, either in the soluble or insoluble form, and re-deposited elsewhere. The deposition of the insoluble material as sediment by the action of gravitation gives rise to the formation of gravel, sand and mud. In order that the soluble material may again take the solid form it is necessary that chemical or organic action should supervene; or that the solvent medium should evaporate.

The rocks now forming under the influence of surface agencies are characterised by an arrangement in layers, usually of small thickness but of considerable horizontal extent. They are the result of the aggregation of mineral particles under the influence of gravitation, and the planes which separate the different layers stand related to the direction in which this force acts and are, in the case of the finer deposits, approximately at right angles to this direction.

The changes which result from the operation of the above agencies are not, however, limited to the actual surface. Meteoric water percolates to great depths and produces directly and indirectly, by means of the substances which it holds in solution, the most profound chemical and physical changes. Oxidation, reduction, solution, hydration, decomposition, and re-composition are constantly going on throughout the rock-masses, and are largely dependent on surface conditions. Springs which issue from the interior are charged with various substances in solution. These substances are the end-result, so far as the water is concerned, of the complex chemical reactions which it has been the means of producing in the rocks through which it has passed. They represent, it must be remembered, a far greater amount of change than the mere solution of so much solid material.

In addition to the subterranean agents of change, which are more or less dependent on surface conditions, there are others which are mainly due to the high temperature of the interior. Masses of molten matter make their way to the surface in connection with volcanic action; hot water, acid and other gases also rise to the surface from great depths under certain circumstances. The operation of these agents on the rocks of the earth's crust cannot be directly examined; but a considerable amount of information may be obtained with reference to them by the application of known chemical and physical laws, and by the observation of the effects produced in the past on rocks which have been exposed at the surface by denudation. Contact metamorphism, produced by the intrusion of masses of eruptive rock, is one of the most important of these effects. It will be described in connection with the rocks themselves.

Another cause which has certainly produced most important changes over extensive areas is the lateral thrust of which there is such striking evidence in many districts. It is now abundantly clear that the solid rocks, in certain cases, yield as plastic bodies—that is by the movement of the constituent particles over each other—under the influence of the powerful stresses which

deform the rock masses. In some cases the movement is accompanied only by a mechanical re-arrangement of the constituent particles, in others by a crushing of these particles, and in others by a molecular re-adjustment. In all cases new structures and in many cases new minerals are developed; so that the original characters of the rocks are more or less obliterated. The term "regional metamorphism" will, in the present work, be applied to the action above referred to.[1]

There yet remain to be considered the rock-producing agencies which depend upon internal heat. The only agencies of this kind which can be directly observed are those connected with volcanic action. Masses of molten material, or, more frequently of molten material charged with crystals, are blown into the atmosphere by the explosive escape of contained gases and vapours, or else well out from the crater or from a fissure in a comparatively quiet manner as a lava stream. The final consolidation of the fragmental material, after it has fallen on the surface, or of the lava current, gives rise to a new rock, entirely different from the rocks already referred to as originating from the destruction of older rocks by surface agencies. New rocks may also arise in consequence of the consolidation of molten material beneath the surface in large masses, veins, and dykes.

We recognise then, two strongly contrasted groups of rock-forming agencies now in operation: (1) those which depend on surface action and give rise to sedimentary, chemical and organic deposits, and (2) those which depend on internal action and give rise to fragmental volcanic rocks, lavas, and crystalline masses of deep-seated origin. We recognise also that the rocks already formed are constantly undergoing change in consequence of changes in their environment. In this way rocks possessing new characters may be produced from pre-existing rocks without the disintegration of the latter by surface agencies, or without their reduction to the molten condition by intense heat. The agents of change may be conveniently classified as follows:—

(1) Those which depend mainly on surface actions; *e.g.* percolation of water charged with various substances in solution.

(2) Those which depend mainly on internal heat; including the action of molten material, hot aqueous solutions and acid gases.

(3) Those which depend mainly on intense mechanical stresses operating upon solid rocks in the earth's crust—regional metamorphism.

---

(1) The conversion of argillaceous deposits into clay-slate, quartzite into quartz schist, ordinary limestone into crystalline marble Baltzer, der Mechanische Contact von Gneiss und Kalk. Berne, 1880, pp. 51—60), and dolerite into hornblende-schist (Teall, Q.J.G.S. Vol. XLI, p. 133), may be quoted as illustrations of this action.

The different kinds of metamorphism may be superposed, or the same kind of metamorphism may affect the same area at different periods. Thus in the Bergen Peninsula (see Rensch, Die fossilien fuhrenden krystallinischen Schiefer von Bergen in Norwegen, 1883), there are crystalline schists, probably of pre-cambrian age, lower palæozoic sediments and eruptive masses of granite, gabbro, &c. All these rocks have been simultaneously affected by post-silurian regional metamorphism; the direction of the most intense pressure being N.W. and S.E. The effect of this pressure has been to produce profound structural and mineralogical changes in the rocks of the district, and to impress on the bedding, cleavage and foliation, a dominant N.E. and S.W. strike; so that a continuous stratigraphical sequence is simulated in what is, in reality, a very complex mass.

If now we direct our attention to the rocks of which the earth's crust is composed we have no difficulty in recognising the fact that a large proportion of them have been produced by the agencies above referred to. We recognise rocks that have been formed by surface agencies—the *stratified rocks;* and others that have been formed by igneous action—the *massive rocks* and their *tuffs*. We recognise also metamorphosed representatives of these two classes.

When, however, we have classified all those rocks about the origin of which there is no doubt, we are obliged to recognise the existence of others which do not fall readily into our scheme of classification. The crystalline schists of archæan age are the most important of these. Some geologists maintain that these schists are portions of the original primitive crust, [1] and that they should be classed with the igneous rocks; [2] others that they are chemical precipitates from a primordial ocean; others that they are the result of a peculiar kind of metamorphism, diagenesis, acting upon the sediments or precipitates of such an ocean; [3] others that they are the result of ill-defined metamorphic processes operating upon ordinary sedimentary rocks, without seriously disturbing, or in any way obliterating, the original order of stratification; [4] and others that they are the result of regional and contact metamorphism operating upon complex systems of massive and stratified rocks. [5]

Having regard to the great difference of opinion which exists between competent observers it appears desirable to establish a third group for the rocks of doubtful origin. [6] This group will include all those rocks which cannot be referred to a place in the above scheme of classification. It may be asserted with confidence that the advance of science will tend to reduce this group.

It will be understood, from what has already been stated, that the author does not recognise the independent existence of a third group of rocks, to which the term *metamorphic* is applicable, of equal importance with the well defined groups which are somewhat imperfectly designated by the terms *stratified* and *massive;* or *aqueous* and *igneous*.

In the present work, the igneous, or massive, rocks will first be considered, then the aqueous or stratified, and lastly, the rocks, which must at present be placed under the head of *incertæ sedis*. Metamorphic rocks, so far as they can at present be recognised, will be described in connection with the original rocks of which they are the metamorphosed representatives.

---

(1) De Lapparent, Traité de Geologie, 1st Edit., page 612.

(2) Roth. Beiträge zur petrographie der plutonischen Gesteine.

(3) Gümbel. Geognostische Beschreibung des Ost-bayerischen Grenzgebirges. Gotha, 1868. 833—845.

(4) Dana. Manual of Geology.

(5) Lehmann. Die Entstehung der alt-krystallinischen schiefer Gesteine. Bonn, 1884.

(6) See Lossen, Op. cit. p. 501.

PART I.

Igneous Rocks.

CHAPTER I.

The Constituents of Igneous Rocks.

IGNEOUS rocks result from the consolidation of molten masses under various conditions. They may occur as tuffs and agglomerates or as massive rocks. Whether a given mass of molten material shall take the form of a fragmental or massive rock will depend entirely on the conditions of consolidation. If the consolidation be effected beneath the surface a massive rock will, in the vast majority of cases, be produced; but if, on the other hand, it be erupted at the surface its final condition will depend on the character of the eruption. A violent paroxysmal eruption, such as that of Krakatoa in 1883, is accompanied by the escape of enormous quantities of aqueous vapour and other elastic fluids, and the consequent production of fragmental rocks on a gigantic scale. The molten material is distended by the escape of the occluded gases, and a large portion of it is reduced to particles so fine that they may be carried great distances by the wind. A quiet eruption, such as that of Mauna Loa in 1880, is accompanied by the welling-out of large masses of molten material which flow down the slopes of the mountain and finally consolidate as massive rocks.

In considering the physical, chemical and mineralogical characters of igneous rocks it will be convenient to select the massive rocks as the types to which the fragmental rocks may be referred. Massive rocks may occur as lava flows, veins, dykes, sheets, laccolites [1] and intrusive masses of irregular form.

If we examine any extensive series of igneous rocks we recognise at once a great diversity in colour, texture and general appearance. Some contain a number of vesicles or cavities; others are solid throughout. The latter may appear homogeneous to the unaided eye or they may be seen to consist, either wholly or in part, of distinct minerals. Rocks which appear homogeneous to the unaided eye may often be resolved, by the examination of thin sections under the microscope, into an aggregate of distinct substances. The constituents of massive rocks so far as they can be determined by macroscopic and microscopic examination may be roughly classified as follows:—

(1) Glass. [2]

(1) G. K. Gilbert. Report on the Geology of the Henry Mountains, U.S. Survey of the Rocky Mountains Region, Washington, 1880, 2nd edition.

(2) Microfelsite (Rosenbusch) and crypto-crystalline matter are not here referred to as distinct substances. The former is isotropic but differs from glass in the presence of distinct flecks and fibres which are so thickly crowded together as to destroy the clearness of the substance. The latter probably consists of matter in one or more of the above conditions but of so fine a grain as to be incapable of resolution in sections of the usual thickness, and with the magnifying power which is generally employed. In many cases matter which appears crypto-crystalline when examined in thick sections and with low powers may be resolved into a micro-crystalline aggregate,

(2) Crystallites.

(3) Microlites, microlitic aggregates, skeleton crystals, crystalline grains, crystalline masses of irregular form, crystals, and crystal fragments.

Glass.—A glass is a homogeneous solid whose external form and internal structure are to a very great extent independent of its chemical composition. A crystal, on the other hand, is a homogeneous solid whose external form and internal structure are related to its chemical composition; to the circumstances under which it has been developed; and in some cases also to the changes which have taken place in its environment since it was produced. The composition of a glass cannot as a rule be expressed by a definite chemical formula. A crystal is of necessity a definite chemical compound. Glass possesses no double refraction, except when subjected to strain.[1] It therefore appears uniformly dark between crossed nicols, as the stage is rotated under parallel rays of polarized light, and gives no interference figure with convergent polarised light. Crystals, on the other hand, unless they belong to the cubic system, invariably possess double refraction in certain directions, and, in those sections which appear uniformly dark between crossed nicols with parallel rays of polarised light,[2] give the interference figures of uniaxial or biaxial crystals in convergent polarised light.

It thus appears that the glassy and crystalline conditions stand, in a certain sense, in opposition to each other. Experiment and observation indicate that the conditions requisite for the formation of a perfect glass are those dependent on the rapid cooling of a perfectly fused mass of rock. Under these conditions definite chemical compounds are unable to individualise themselves by crystallisation. The element of time is involved in crystal-building, and here that element is wanting.

The crystalline constituents of igneous rocks may be made to assume the glassy condition by fusion and rapid cooling. When this is done the specific gravity of the glass is always found to be less than that of the crystal from which it is produced. The following cases serve to illustrate this point.[3]

	Specific Gravity of the Crystal.	Specific Gravity of the Glass.
Quartz	2·663	2·228
Olivine	3·381	2·857
Sanidine	2·58	2·38
Orthoclase	2·574	2.328
Oligoclase	2·66	2·258
Labradorite	2·689	2·525
Hornblende	3·216	2·825
Augite	3·267	2·803

doubly-refracting particles and a glassy or micro-felsitic base by the use of thinner sections and higher powers.

(1) F. Rutley. On strain in connection with crystallisation and the development of perlitic structure. Q.J.G.S.. Vol. XL., p. 340.

T. Waller. The phenomena of strains observable in obsidian, G.M., 1885, p. 91.

(2) A section of a biaxial crystal cut at right angles to one of the optic axes, when examined with an ordinary petrographical microscope, does not remain dark in all positions as the stage is rotated. This is owing to the fact that the rays of light are not strictly parallel.

(3) Compiled from Roth's allgemeine und chemische Geologie. Vol. II., p. 52. Berlin, 1883. The student is referred to this work for fuller detail and for references to original papers.

The same relation necessarily holds between the specific gravity of the glass formed by the fusion of a holocrystalline rock and that of the rock itself.

	Specific Gravity of Rock.	Specific Gravity of Glass.
Granite	2·680	2·427
Syenite	2·710	2·43
Diorite	2·779	2·608
Porphyrite	2·763	2·486
Gabbro	2·898	2·641

We may conclude from these facts that the devitrification of a glassy rock is accompanied by an increase in density, and that, in the case of the complete devitrification of a glass having the composition of the granite in the above table, the increase would be about 11 p.c.[1]

Since an increase in density accompanies devitrification, it may reasonably be inferred that pressure will tend to bring about devitrification.

The most perfect illustration of a natural glass is furnished by fulgurite,[2] the material which results from the fusion of rocks and minerals by lightning.

An eruptive mass of any composition may assume the glassy form under suitable conditions of consolidation. Some rocks, such as obsidian and tachylite, are almost entirely formed of glass; others are composed of crystals, crystalline grains and crystal fragments embedded in a glassy base. Crystallites, microlites, microlitic aggregates and skeleton crystals are frequently present in the glassy rocks, and in the glassy base of the semi-crystalline rocks.

Crystallites are bodies formed in consequence of the attempts of some definite chemical compound to crystallise under unfavourable circumstances. They represent matter in a state which is intermediate between that of a glass and that of a true crystal. They occur not only in natural rocks but also in various artificial products; such as slags, blowpipe beads and the refuse material of glass works. The conditions of their formation have been determined experimentally by Vogelsang, a brief account of whose researches will now be given.

After many trials sulphur was the substance finally selected by Vogelsang for his experiments. This substance is readily soluble in bisulphide of carbon, out of which it crystallises in the rhombic form. If the process of crystallisation be followed under the microscope nothing definite can be made out as to the initial stages of crystal-development. The first objects which appear are definite crystals of sulphur, and these grow by accretion in the usual manner. If, however, the solution of sulphur be thickened with Canada balsam, then, provided the proper proportions of the different substances have been employed, some very interesting phenomena may be observed as the

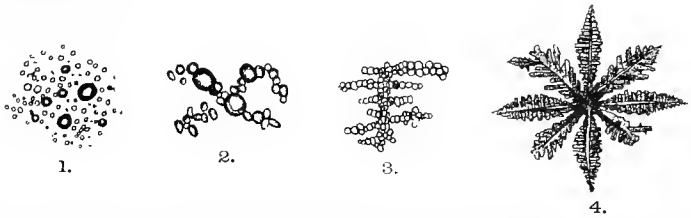
(1) Mr. Allport has described some ancient devitrified pitchstones and perlites from Shropshire, and, in his paper (Q. J. G. S., Vol. XXXIII. p. 449), he gives an analysis of one of these rocks, and quotes for comparison the analyses of two Hungarian glassy rocks. There are no essential differences between the three analyses. On referring to the work from which the analyses of the Hungarian rocks are quoted, it will be found that their specific gravities are 2·428 and 2·384. That of the devitrified Shropshire rock is 2·62. The difference between the specific gravities of the devitrified and glassy rocks implies an increase of 9 p.c. during the process of devitrification.

(2) A. Wichmann. Ueber Fulgurite. Z.D.G.G., 1883, p. 849.
J. S. Diller. Fulgurite from Mt. Thielson, Oregon. A.J.S., 1884, p. 252.
F. Rutley. On Fulgurite from Mt. Blanc. Q.J.G.S., vol. XLI., p. 152.

bi-sulphide of carbon evaporates. Minute fluid spheres of a deeper colour than the general mass of the liquid arise in the medium, and grow by mutual absorption. They finally consolidate as clear, transparent isotropic bodies which Vogelsang has termed *globulites*. Fig. 1.[1] It is impossible to ascertain the composition of these bodies with absolute certainty on account of their minuteness; but there seems no reason to doubt the conclusion of Vogelsang that they are portions of the Canada balsam which are richer in sulphur than the surrounding substance. They evidently arise in consequence of the attempt of sulphur to crystallise under unfavourable circumstances. Similar bodies may be observed in many natural and artificial glasses, although the crystallising compounds must be very different in the different cases.

Under certain circumstances the mass of sulphur and Canada balsam solidifies with the formation of globulites only ; but under other circumstances additional phenomena may be observed. When the resistance offered by the medium is too great to prevent the union of globulites, but not too great to prevent their approach, they become united into more or less definite forms. (Figs. 2 & 3.) A linear grouping gives rise to the form to which Vogelsang gave the name of *margarite*. A rectangular grouping is not uncommon. A study of the various modes of grouping led Vogelsang to the conclusion that there are, in each sulphur globulite, three directions or axes of principal attraction. The building-up of compound forms, under the influence of these attractions, naturally leaves the surrounding space free from globulites.

Sometimes the globulites become fused as it were at the points of contact. In this way rod-like bodies, termed *longulites*, arise. Forms of great beauty and complexity are often produced by the union of globulites, longulites and margarites, in various ways. It must be remembered that all these forms are isotropic. They cannot, therefore, be regarded as ill-formed crystals. The moment a crystal of sulphur appears it may be recognised by its double-refracting properties.



1. 2. 3. 4.

Microlites, &c.—Microlites differ from crystallites in possessing the internal structure of true crystals. They react on polarised light exactly as a crystal does. They are always minute, and their forms are usually more or less imperfect. Almost all the minerals which occur as common constituents of igneous rocks are found occasionally in the condition of microlites. Some of the commonest forms of microlites are represented below :—

Fig. 5. *(After Zirkel.)*

(1) Figs. 1, 2, 3 and 4 are taken from Vogelsang's "Die Krystalliten." Bonn.

Microlites often show a tendency to build up compound forms possessing more or less regularity. This is well seen in the Arran pitchstone,[1] where minute needle-like bodies (belonites) group themselves so as to produce most beautiful arborescent aggregates, reminding one of the forms assumed by water as it crystallises on a window frame. (Fig. 6.)

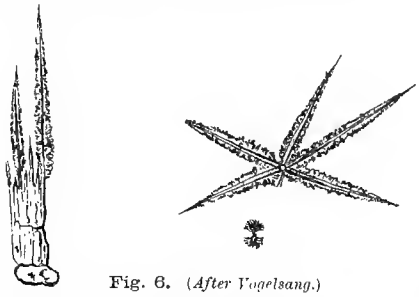


Fig. 6. (*After Vogelsang.*)

Feathery forms and skeleton-crystals are also produced by the aggregation of microlites. (Fig. 7.)

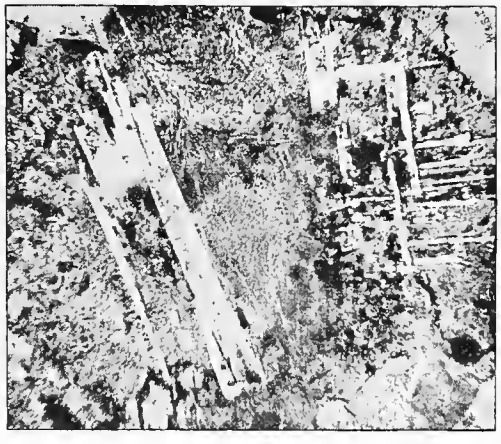


Fig. 7, Skeleton Felspars in the ground-mass of the Cleveland Dyke, Preston. Magnified 170 diameters.

Another mode of aggregation is that known as the spherulitic. True spherulites consist of crystalline fibres which radiate from some central point and extinguish light under crossed nicols when their long axes lie parallel with the vibration planes of either the polariser or analyser. They therefore give rise to a black cross which remains stationary as the stage is rotated.

It sometimes happens that spherulitic aggregates may be formed by the inter-crystallisation of two minerals; such, for instance, as quartz and felspar. In these cases, the axes of elasticity in the different elements of the spherulite may have different positions in relation to the spherulite as a whole, and the structure may give rise to more or fewer arms than the number characteristic of true spherulites, and their arms may not lie parallel with the vibration planes of the nicols. Such structures Professor Rosenbusch[2] proposes to call

(1) S. Allport. On the microscopic structure of the Pitchstones of Arran. G.M., 1872. p. 1.
(2) Zusammensetzung und Structur granitischer Gesteine. Z.D.G.G. 1876, p. 369.

pseudo-spherulites. They are especially characteristic of the granophyres (Rosenbusch), of which the rock from the top of Carrock Fell, Cumberland, may be taken as the type in this country.

Crystals, Crystalline Grains, &c.—When a definite chemical compound crystallises out of a molten magma it assumes, under certain conditions, a definite geometric form, which is characteristic of the substance under those conditions. It very often happens, however, that the larger crystalline constituents of igneous rocks are devoid of this definite external form. This is due to a variety of causes. Where a number of minerals are simultaneously produced in juxta-position mutual interference prevents the development of perfect crystalline forms. This is well seen in the case of plutonic rocks; such as gabbro, diorite and granite. When the minerals in a rock have been formed at different times, those first produced usually show the most perfect development of crystalline faces.

Mechanical actions frequently break up the first-formed crystals in an igneous magma and accordingly we find, in many lavas and tuffs, the fragments of once perfect crystals. Again, the imperfect forms of certain minerals, as for instance the quartz grains of certain rhyolites and quartz-felsites and the hornblende-crystals of certain andesites and porphyrites, is probably due to a corrosive action of the magma on more or less perfect crystals. The process of crystal-building in a mass of molten material is, in most cases, extended over a long period of time during which the chemical and physical conditions are constantly changing. Crystals, like organisms, stand in the closest relation to their environment, and are liable to be modified by every change in the latter. It is not surprising, therefore, to find evidence of such modifications in the internal structures and external forms of the mineral constituents of igneous rocks.

A typical crystal should be perfectly homogeneous. It rarely happens, however, that this condition of things is actually realised. Inclusions of foreign matter are usually present, and as these often throw important light on the conditions under which the crystal was developed, or on the metamorphic changes to which it has been subjected, since its formation, they are of great interest to the petrographer. In order that conclusions may be drawn as to the origin of rocks from the phenomena presented by the inclusions in the minerals of which they are composed, it is obviously necessary that the minerals should have been formed at the same time as the rocks, and that the inclusions should have been formed at the same time as the minerals. Now there are original and secondary minerals and there are original and secondary inclusions; and it is not always possible, in the present state of our knowledge, to be certain as to which of these classes any particular mineral or inclusion belongs. Again, if we agree that an igneous rock attains individuality at the time of final consolidation, then the original minerals belong to two classes—those formed at the time of consolidation and those formed anterior to it. If the semi-liquid mass has moved since the development of the former then the inclusions which they contain throw no light on the conditions of final consolidation. Great care is therefore necessary in drawing inferences from the phenomena of inclusions.

The conditions which determine the development of inclusions during the growth of crystals have been investigated by Dr. SORBY and the results published in his classic paper on "The microscopical structure of crystals indicating the origin of minerals and rocks" (1)

In his experimental work Dr. SORBY employed aqueous solutions of such substances as the chlorides of sodium and potassium, bichromate of potash, and sulphate of zinc. He found that when crystals are deposited from solution at ordinary temperatures they usually contain a number of cavities full of the mother-liquor. When thay are deposited at high temperatures, say at the temperature of boiling water, and are allowed to cool, the cavities are no longer full of liquid but contain a small bubble due to the contraction of the liquid subsequent to its enclosure. When the crystals are formed at the surface of the solution, so as to be in contact with both air and water, then they contain gas- as well as liquid-inclusions.

When crystals of one salt are formed from a hot solution containing a second salt, inclusions may be produced which, at ordinary temperatures, contain not only a portion of the mother liquid and a bubble, but also crystals of the second salt. Thus, from a solution containing chloride of sodium and bichromate of potash, crystals of common salt with inclusions full of the mother-liquor may be formed at 100° C.; but at ordinary temperatures these inclusions will contain, if suitable proportions of the two salts have been employed, a liquid, a bubble and a crystal or crystals of bichromate of potash.

The forms and sizes of inclusions vary very considerably in different cases. The forms may be more or less spherical, elliptical, irregular, or bounded by planes corresponding to the external faces of the containing crystal. In the last-mentioned cases they are termed negative crystals.

The number of inclusions in a crystal appears to depend on the rate of growth. Other things being equal, the more rapid the growth the more abundant are the inclusions. The size, on the other hand, varies in an inverse manner. The more rapid the growth the smaller are the inclusions.

Inclusions are distributed throughout the crystal in which they occur in various ways. It rarely happens that the distribution is perfectly uniform. Very often the inclusions are crowded together in certain zones which run parallel to the external crystalline faces, and thus serve to indicate, in all probability, variations in the rate of crystalline growth. Sometimes they are arranged in planes which do not bear any definite relation to the form of the crystal, and sometimes they are scattered throughout the crystal without any apparent regularity.

At first sight it might be thought that there is no connection between the phenomena of crystal-building in an aqueous solution and the formation of igneous rocks. This, however, would be a mistake. The growth of a crystal during the process of cooling in an igneous magma is strictly comparable with the growth of a crystal in a supersaturated saline solution. Inclusions are formed in precisely the same way and in accordance with precisely the same laws. When first formed they are liquid inclusions, but as the mass cools down they become solid. In this way the glass- and stone-

(1) Q.J.G.S., 1858, p. 453.

inclusions of Dr. Sorby are formed. Like the fluid inclusions, already referred to, they frequently contain bubbles.

Crystals formed by sublimation contain only gas- and vapour-inclusions. Such inclusions, however, are by no means limited to crystals formed in this way. Liquids possess the power of absorbing gases to a certain extent. Water will take up a certain amount of oxygen, nitrogen, and carbon dioxide from the air; molten silver will absorb twenty-five times its volume of oxygen; slags contain a considerable amount of gas. When solidification occurs the dissolved gases are either expelled, or included mechanically in the solid. It therefore happens that gas- and vapour-inclusions are frequently associated with solid- and fluid-inclusions.

In recognising the various kinds of inclusions under the microscope the breadth of the black border, which marks the outline of the inclusion or of the bubble, is of the greatest utility. This border is due to the refraction and total reflection of light which occurs at the surface of contact of two media having different refractive indices; and, other things being the same, its breadth is dependent on the difference between these indices. If the refractive index of empty or gas-filled space be taken as 1, that of quartz is 1·547; of glass (obsidian), 1·488; and of water, 1·336 [1]

The external boundary of a glass inclusion in quartz (difference in refractive indices ·059), will therefore be less marked than that of an ordinary liquid inclusion (diff. = ·211), whereas the boundary of the bubble will be more marked in the former (diff. = ·488) than in the latter case (diff. = ·336).

Dr. Sorby draws the following conclusions from his experiments and observations on artificial products.

(1) Crystals possessing only inclusions containing water, more or less saturated with various salts, were formed by being deposited from solution in water.

(2) The relative size of the bubbles in normal fluid inclusions depends on the temperature and pressure at which the crystals were formed, and may in some cases be employed to determine the actual or relative temperature and pressure.

(3) Crystals containing only glass- or stone-inclusions were formed by being deposited from a substance in the state of igneous fusion.

(4) Crystals containing only gas- or vapour-inclusions were formed by sublimation, or by the solidification of a fused homogeneous substance; unless they are liquid inclusions that have lost all their liquid.

(5) Other circumstances being the same, crystals containing few inclusions were formed more slowly than those containing more.

(6) Crystals possessing liquid-inclusions which contain a variable amount of gas or vapour, and pass gradually into gas or vapour inclusions, were formed under the alternate presence of a liquid and a gas.

(1) Zirkel. Mikroskopische Beschaffenheit, &c. 1873, p. 71.

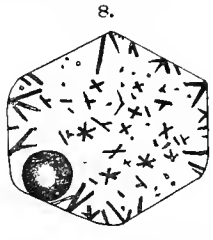
(7) Crystals containing liquid and glass (or stone) inclusions were formed under great pressure by the combined action of igneous fusion and water.

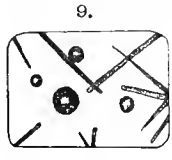
(8) Crystals having the characters of 6 and 7 combined were formed under great pressure by the united action of igneous fusion and water, alternating with vapour and gas, so as to include all the conditions of igneous fusion, aqueous solution and gaseous sublimation.

The above conclusions are unquestionably of great value and interest; at the same time it must be admitted that when we attempt to apply them to the minerals of eruptive rocks, for the purpose of ascertaining how those rocks were formed, we are brought face to face with very great difficulties. They can only be applied, for instance, in cases where there is no doubt as to the original character of the minerals and the inclusions. It is assumed, in the above statement, that all inclusions are original. Subsequent research has, however, tended to show that secondary inclusions are by no means uncommon. The different kinds of natural inclusions will now be described, with special reference to the igneous rocks.

Glass Inclusions.—Glass inclusions are especially abundant in the porphyritic crystals of volcanic rocks; as, for instance in the felspars of rhyolites, andesites, and porphyritic basalts. In these cases they may, without doubt, be regarded as original; or, in other words, as owing their origin to the enclosure of portions of the mother-liquor during the growth of the crystal, and the subsequent consolidation of this as the rock cooled down to the ordinary temperature.

These inclusions are especially common in those rocks which contain a glassy base. Sometimes the glass of the inclusions is similar to that forming the base of the rock. This is the case with the inclusions in the sanidine crystals of the Arran Pitchstone.[1] Sometimes, on the other hand, the glass of





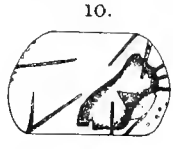


Fig. 8.[2] Glass-inclusions in the felspar of a porphyritic pitchstone from Arran, containing microlites and a bubble. Magnified 300 diameters.

Fig. 9. Ditto, containing several bubbles. Magnified 330 diameters

Fig. 10. Ditto, with a distorted bubble, into which the microlites project. Magnified 600 diameters.

the inclusions is darker in colour than that of the rock;[3] a fact which may be taken as indicating a difference in chemical composition, and probably a

(1) Sorby. Microscopic structures of crystals. Q.J.G.S., vol. XIV. 1858, p. 476.
S. Allport. On the Pitchstones of Arran. G.M., vol. IX., 1872, p. 4.

(2) Figs. 8, 9 and 10 are taken from Dr. Sorby's paper.

(3) F. Zirkel. Microscopical Petrography of the 40th Parallel. 1876, p. 226.

greater amount of iron and the bases usually associated with it, in the glass of the inclusions. The feature referred to may, as ZIRKEL points out, be readily explained by the variations in composition, which must take place in the fluid magma as crystals separate out of it. The general effect of this separation, as we shall see later on, is to deprive the magma of the bases lime, iron and magnesia, and consequently to leave it richer in silica and the alkalies.

The glass of an inclusion very frequently contains crystallites, microlites and crystals, similar to those which occur in the ground-mass of the rock. These may sometimes have been enclosed along with the glass; but, in the majority of cases, they are unquestionably due to crystallising action set up in the glass subsequent to its enclosure. Good illustrations of these are also to be seen in the Arran pitchstones already referred to.

Another feature usually, but not invariably, observed in glass inclusions is the presence of one or more bubbles. These bubbles may either represent a vacuum or the presence of a certain amount of gas. The common form is spherical or elliptical, but sometimes the bubbles are seen to be curiously distorted (Fig. 10), and when this is the case they give evidence of the solid nature of the contents of the inclusions. When microlites are present they are sometimes seen to project into the interior of the bubbles. In all cases these bubbles appear, under the microscope, to be surrounded by a broad black border, due to the marked difference in the refractive indices of the contents of the bubble and the surrounding glass. Usually the bubble is within the boundary of the enclosure, but sometimes it projects into the crystal substance.

Dr. SORBY regards the bubbles as due to the unequal contraction of the enclosed magma and the surrounding crystal as both cool down to the temperature at which the observation is made; but Professor ZIRKEL[1] holds that this explanation is certainly not true in all cases. If it were true, there should be a constant relation between the size of the bubble and that of the inclusion in the crystals of the same rock or, at any rate, in the same crystal; but this is not the case. Sometimes there is no bubble, at other times the bubble occupies the greater portion of the enclosed space; and every possible gradation between these extremes may be observed. He is inclined, therefore, to regard the bubble as representing a portion of gas which has been disengaged from the magma, and enclosed along with the glass. The presence of a bubble which is half in the glass and half in the surrounding crystal certainly seems to require some such explanation as this. It is, of course, quite possible that the explanation of Dr. SORBY may apply in certain cases, and that of PROFESSOR ZIRKEL in others.

The forms of glass inclusions are liable to a considerable amount of variation. Sometimes they are spherical, or elliptical; at other times they are extremely irregular. One form which is not at all uncommon is that of a negative crystal. In this case the actual form is of course dependent on that of the containing crystal; it is in fact an inverse reproduction of the latter. Such inclusions may frequently be observed in the quartz of certain pitchstones and felstones, as for instance those from Arran; in the felspars and augites of many rocks; and in the lencites of Vesuvian lavas.

(1) Mikroskopische Beschaffenheit, &c. 1873, p. 67.

The arrangement of the inclusions in the crystal also varies in different cases. Sometimes they are crowded together in the centre of a crystal, sometimes they form a band round the periphery, and very frequently they are arranged in a zonal manner; the zones corresponding in form with that of the crystal itself. Five or six distinct zones may sometimes be detected, as for instance, in the felspars of the andesites. It is impossible to avoid the conclusion that the zonal arrangement indicates variations in the conditions of crystal-growth; and it is probable that, as in Dr. SORBY's experiments, it is the rate of growth that determines the number of inclusions. The more rapid the growth the greater the number; the slower the growth the smaller the number. With regard to the precise way in which inclusions arise we are, to a very great extent, in the dark. Crystals grow by accretion; that is by the addition of matter to their external surfaces. If this addition be regular and constant during the period of growth then a homogeneous crystal will be the result; but if, for some unknown reason, the addition of material be interrupted at certain points, then indentations will be formed on the growing surfaces and these indentations may become inclusions by the growing together of their walls as the crystal increases in size. Dr. SORBY's observations on growing salt crystals led him to the conclusion that this was the way in which inclusions originate. It is well to note however that they may possibly, in certain cases, be formed in another way. The quartz crystals of rhyolites, felsites, and pitchstones are regarded as having been formed from an igneous magma, and yet they frequently present appearances which imply that the magma has exerted a solvent action on the crystal. Thus the angles are usually rounded off, and the groundmass of the rock often penetrates into the crystal in the form of miniature bays, gulfs and fiords. If both these views, which at first sight appear to be mutually destructive, be correct, we are driven to the conclusion that alterations in the physical conditions, and possibly also in the chemical composition of a magma, may cause a crystal to be developed at one time, and corroded at another; and if repeated changes in the conditions occur, so that a period of growth follows one of corrision, it is quite possible that inclusions may be formed by the growth and completion of corroded crystals. These considerations naturally lead us to the subject of secondary glass-inclusions.

For a long time it was supposed that glass inclusions must of necessity be original. It has recently been shown by M. K. von CHRUSTSCHOFF [1] that this is not the case. Secondary glass inclusions are found in the minerals of certain rocks which have been acted upon by igneous magmas. They occur for instance in fragments of sandstone, granite, gneiss and other rocks, which have been caught up by molten material during its eruption or intrusion. They have also been observed at the contact of eruptive masses and the surrounding rocks [2] and have been produced artificially by subjecting fragments of

(1) Über secundäre Glaseinschlüsse. T.M.M., Neue Folge, Vol. IV., p. 473, and Vol. VII., p. 64.

(2) At the contact of granite and melaphyre, Petrographische Studie am Granit von Predazzo. A. Sigmund. J.G.R., vol. XXIX.. 1879, p. 311. See also CHRUSTSCHOFF, Über den Granit des Monte Mulatto, Predazzo. N.J., 1885, Band II., p. 66.

sandstone, granite, &c., to the action of fused masses of igneous rocks for one or two hours.

A basalt-magma appears to be the one which is most capable of developing secondary glass inclusions, and quartz is the mineral in which such inclusions are most readily developed. According to M. CHRUSTSCHOFF they may be formed in two ways:—(1) by the passage of the magma into cracks and cavities in the mineral, and the subsequent sealing up of the channels of communication, and (2) by the fusion of enclosed minerals. A basic magma will act chemically on quartz and take up a portion of its substance until it becomes saturated with silica. In this way pre-existing cracks and cavities may be enlarged. Many of the secondary inclusions have the form of negative crystals, a fact which shows that in all probability the solvent action is exerted unequally in different directions. The absence of any channel connecting the inclusion with the exterior is explained, according to M. CHRUSTSCHOFF, by the deposition of secondary silica from the magma during the process of cooling. Such silica would necessarily be deposited in optical continuity with the original crystal, and might therefore obliterate the connecting channel. In certain cases there is direct evidence of the deposition of such secondary silica. When glass inclusions arise in consequence of the fusion of minerals contained in the original crystal, the absence of a connecting channel requires of course no explanation.

In studying glass inclusions in microscopic sections it must of course be remembered that it is not always possible to determine whether a given mass of glass which is entirely surrounded by crystal-substance is, in reality, an inclusion. It may be that the section has been cut in such a direction as not to expose the channel of communication.

FLUID INCLUSIONS.—The existence in certain crystals of cavities containing liquids and gases has long been known. In 1822 SIR HUMPHREY DAVY [1] proved that the liquid in a large cavity, in a certain quartz crystal, was water; and that the bubble which could be seen to move about like that of a spirit level, always keeping to the uppermost side of the cavity, as the position of the crystal was changed, was either nitrogen or a vacuum. SIR DAVID BREWSTER [2] recognised the existence of fluid inclusions in a large number of minerals and discussed the bearing of these inclusions on questions relating to the origin of the minerals in which they occur. He also detected the existence of two immiscible liquids in certain cavities in topaz and other minerals, and observed that one of these liquids was twenty times more expansible with increase of temperature than water.

It was not, however, until Dr. SORBY turned his attention to the subject, and published his classic paper on "The microscopical structure of crystals indicating the origin of minerals and rocks," that fluid inclusions were known to be widely distributed in the ordinary rock-forming constituents, and to have an important bearing on geological problems.

The fluid inclusions which occur in the constituents of rock-masses are

(1) Phil. Trans. Roy. Soc., 1822, p. 367.

(2) **Trans. Roy.** Soc. Edin. Vol. X., pt. 1, p. 1. 1824.

usually very minute, and therefore visible only when thin sections of the rocks are examined under the microscope. The largest are usually about ·006 mm. in diameter; the smallest are visible only as specks when viewed with the highest powers of the microscope. They are most abundant in quartz, but occur also in felspar, nepheline, elæolite, leucite, augite, chlorite, olivine, topaz, cordierite, vesuvian, beryl, spinel, sapphire, calcite, gypsum, fluor-spar, rock-salt, cassiterite and zinc-blende. If we consider the distribution of fluid inclusions in the different classes of rocks, we are struck by the fact that they are especially characteristic of the plutonic rocks, such as gabbro, diorite and granite, and the crystalline schists. They are rare or absent in rocks of the volcanic group. Speaking generally we may say that fluid and glass inclusions bear a sort of inverse relation to each other so far as distribution is concerned. Where glass-inclusions are common fluid inclusions are either very rare or altogether absent. We do occasionally find glass- and stone-inclusions in the minerals of certain granites and fluid-inclusions in those of volcanic rocks, as for instance in the olivine and leucite of certain lava streams; but the rarity of these occurrences only serves to emphasize the general truth of the above statement, and it must also be remembered that in these exceptional cases the minerals in question have probably been developed before the actual eruption of the lava.

The relative proportion of the fluid- and glass-inclusions has been supposed by some petrographers to stand in relation to geological age; the fluid inclusions being regarded as especially characteristic of the older and the glass-inclusions of the younger rocks.(1) The supposed fact has been explained by reference to changes in the physical condition of the planet during the period of time represented by our geological records. That such changes have occurred, may be admitted; but that we have any evidence of them in the fact here referred to appears to the present writer extremely improbable. The result is obtained by comparing plutonic with volcanic rocks; or, in other words by comparing the rocks which have consolidated at great depths and under great pressure with the surface products of volcanic action. If we compare the plutonic rocks of different periods with each other, and the volcanic rocks of the different periods with each other, the supposed fact disappears. Fluid inclusions are equally abundant in the plutonic rocks of all ages, and glass-inclusions are equally abundant in the volcanic rocks of all ages. Considerable light is thrown on this subject by a paper by Messrs. Hague & Iddings on "The Development of Crystallisation in the Igneous Rocks of the Washoe district" (2) The authors show that the diabase and diorite of this region are the granular representatives of the porphyritic augite- and hornblende-andesites, and shade into them in a perfectly gradual manner. Glass-inclusions occur in the latter, fluid-inclusions in the former rocks.

Fluid inclusions vary considerably in form. They may be spherical, elliptical, irregular or bounded by planes corresponding to the faces of the containing crystal.

(1) C. Frenzel. Ueber die Abhängigkeit der mineralogischer Zusammensetzung und Structur der Massengesteine vom Geologischen Alter. Zeit. f.d. Gess. Naturw. Bd. LV., 1882. p.1.

(2) Bulletin of the U.S. Geological survey. No. 17.

Fig. 11. Fluid Inclusions (*After Sorby*).

(*a*) Fluid inclusion in quartz of Aberdeen granite. Magnified 2000 diameters.

(*b*) Group of fluid inclusions in quartz of granite at St. Austel, Cornwall. Magnified 200 diameters.

(*c*) Fluid inclusion, in the form of negative crystal, containing a bubble and a crystal of salt, in quartz of granite from Ding Dong Mine, Cornwall. Magnified 2000 diameters.

The number of inclusions is also liable to great variation. Sometimes they are scattered sparsely through the crystals, at other times they are collected together in such numbers as to give them a cloudy aspect. Dr. SORBY says [1]:—"In many granites the fluid cavities are so numerous in the quartz, that on the average they are not above the $\frac{1}{10000}$ of an inch apart. This agrees with the proportion of a thousand millions to a cubic inch, and in some cases they must be more than ten times as many."

Under the microscope it is possible to recognise, in the larger cavities, the existence of one and more rarely of the two liquids and a bubble. In the larger cavities the bubbles may usually be caused to move, like those of spirit levels, by placing the microscope in a horizontal position and rotating the stage. In the smaller cavities, which contain bubbles varying from $\frac{1}{10000}$ to $\frac{1}{60000}$ of a inch, the bubbles frequently change their positions without any variation in the position of the slide. Sometimes this movement, which is often termed the Brownian movement, is merely a kind of vibration; at other times the bubble wanders about all over the cavity in an apparently spontaneous manner. The most minute bubbles show the most rapid movement.[2] It is, however, of great utility to the petrographer as furnishing indisputable evidence of the fluid nature of the inclusions in which it occurs. In addition to the bubble, cubical and sometimes also prismatic crystals may occasionally be observed in these inclusions.

Great care has been exercised by SORBY, VOGELSANG, and PFAFF in determining the nature of the contents of the fluid inclusions. SORBY expelled the fluid contents by heating small fragments in a long glass tube, one portion of which was kept cold by a mixture of ice and salt. He observed that a solid substance was condensed on the cold part of the tube which possessed the crystalline properties and thawing point of ice. He also washed the powdered material with pure water and tested the solution thus formed with various reagents. In this way he established the existence of the chlorides of sodium and potassium, the sulphates of sodium, potassium and calcium, and sometimes also of free acids which may, however, have been produced by the partial decomposition of the salts by the heat necessary to expel the liquids from the inclusions. The general conclusion of SORBY is that the liquid present in the cavities of the constituents of plutonic rocks is usually water charged with the above-mentioned salts in solution.

(1) Op. cit., p. 486.

(2) For a discussion as to the cause of this movement see HARTLEY, Proc. Roy. Soc., vol. XXVI., pp. 137 and 180.

Vogelsang and Geissler [1] applied the spectroscope to the determination of the fluid in the inclusions. Their experiments were principally made on the well-crystallised minerals of veins and drusy cavities, and therefore have not such a direct bearing on geological problems as those of Dr. Sorby. They clearly proved that the expansible substance first noticed by Sir David Brewster, and observed by the authors in quartz, topaz and amethyst was liquid carbon dioxide. In one experiment quartz from the granite of Johann Geordenstadt, Saxony,[1] was used, and the inclusions were found to contain water and a small amount of carbon dioxide. The latter substance, however, could not be detected in the liquid form when thin sections of the granite were examined under the microscope. The same authors also constructed an apparatus for examining the effects of heat in expanding the liquid of inclusions while the object was being examined under the microscope, and thus proved that in cavities containing liquid carbon dioxide, the bubble disappeared at 32° C., *i.e.* at about the critical point for this substance. The expansibility of carbon dioxide, and the disappearance of the bubble at about 32° C. furnish a ready method of determining the existence of this substance in microscopic inclusions. The critical point as determined by the disappearance of the bubble in fluid inclusions is, however, not perfectly constant. Thus Hartley [2] found, in the specimens which he examined, that it varied from 27·27° C. to 33·7° C. According to the experiments of Dr. Andrews it is 30·92° C.

Pfaff [3] constructed an ingenious apparatus for estimating the amount of water mechanically enclosed in the minerals of certain rocks. It consisted of a pestle and mortar, so arranged that a rock or mineral could be pulverised in a closed space through which a current of perfectly dry air was passing. He examined, by means of this apparatus, granite from several localities, syenite, porphyry, gneiss, mica-schist, lavas from Vesuvius and Etna, and obsidian from Iceland. The granitic rocks and the schists invariably yielded water; the actual amount varying from 0·11 p.c. in the case of syenite from Meissen to 1·8 p.c. in that of a mica schist from Davos. The lavas and obsidian gave only negative results. It thus appears that the experiments of Pfaff agree with the results of microscopic examination. The minerals of plutonic rocks and the crystalline schists frequently abound in fluid cavities, while those of lava are generally free from them.

Attempts have been made to determine the conditions of temperature and pressure under which rocks have been formed by considering the phenomena presented by the fluid inclusions. In Dr. Sorby's experiments on the formation of inclusions in salt crystals, it was shown that bubbles arise in consequence of the difference in the contraction of the enclosed liquid and the enclosing crystal, as both cool down from the temperature at which the crystal was formed. In these cases the ratio of the volume of the bubble to that of the liquid is constant for all inclusions formed under the same conditions. If

(1) P. A. Vol. CXXXVII., p. 56. 1869.

(2) Jour. Chem. Soc. 1876, vol. II. p. 237.

(3 Über den Gehalt der Gesteine an mechanisch eingeschlossenem Wasser und Kochsaltz. P.A. Vol. CXLIII., p. 610.

the bubbles observed in the fluid inclusions of the minerals in rocks are produced in the same way, then the ratio above referred to must also be constant, and must bear some relation to the temperature and pressure at which the minerals were formed.

The following equation, based on numerous experiments, expresses this relation according to Dr. SORBY.

$$v = (Bt + Ct^2)(1 - \cdot 00000271\ p) - \cdot 00000271\ p.$$

Where v = volume of bubble estimated in terms of the liquid which is taken as unity.

t = temperature at which the mineral was formed.

p = pressure over and above that which would be naturally due to water vapour at a temperature t.

B and C are constants which depend on the nature of the liquid, and which have been determined experimentally by Dr. SORBY for water and certain saline solutions, such as those which occur in liquid inclusions.

In this equation we have two variable quantities, only one of which (v) is known in the case of the minerals occurring as rock constituents. The temperature can only be ascertained when the pressure is known, or the pressure when the temperature is known. Assuming that granites are formed at a temperature of 360° C. for reasons given in the paper, but which need not here be considered, DR. SORBY has endeavoured to determine the pressure under which different varieties have been formed.

Mr. CLIFTON WARD applied the same method to the granites of the Lake District.(1)

It is much to be regretted that more extended observations have not tended to establish the general applicability of this method, or to give confidence in the accuracy of results obtained by means of it. It is based on the assumption that water and water-vapour are the only fluids present in the inclusions—an assumption which in many cases is probably incorrect. The experiments of VOGELSANG and GEISSLER for instance proved the existence of carbon dioxide in granite of Johann Geordenstadt. Again, the observations of Mr. PHILLIPS(2) and others tend to show that the constancy in the ratio of the volume of the bubble to that of the liquid, which is absolutely essential to the applicability of the method, does not exist; and that every gradation may be found in the same rock, or even in the same mineral, between inclusions which are nearly or quite full of liquid, and others which are empty or occupied only by a gas.

Messrs. RENARD and DE LA VALLÉE POUSSIN(3) have devised a method for determining the temperature at which certain rocks have been formed depending upon the solubility of salt in water. Liquid inclusions containing cubic crystals of common salt occur in the diorite of Quenast, Belgium. In one of these the volume of the liquid was estimated at ·0000002198687 cubic mm., and that of the salt at ·0000000098003 cubic mm. REGNAULT ascertained by experiment that the solubility of sea salt in water increases in direct proportion to the temperature between 0°C. and 120°C. and that at 0°C.

(1) Q. J. G. S., vol. XXXI., 1875, p. 388.

(2) On the Rocks of the Mining Districts of Cornwall. Q. J. G. S., Vol. XXXI., p. 332. See also ALLPORT. Q. J. G. S., Vol. XXXII., p. 413.

(3) Mémoire sur les Roches dites Plutonniennes. Brussels, 1874.

100 grammes of water require 35·5 grammes of salt in order to saturate the solution. If the law of REGNAULT holds good at higher temperatures, then a temperature of 307°C. would be required to enable the liquid in the above-mentioned cavity to dissolve the salt crystal.

Unfortunately, the assumptions involved in this method, as in that of SORBY, are so doubtful that little confidence can be placed in the numerical result. That REGNAULT's law should hold good with sufficient accuracy to yield even approximate results so far above the point to which it has been experimentally verified, and under such enormous pressures as exist in the earth's crust—pressures, be it remembered, which may be vastly in excess of that due to the tension of water-vapour at the calculated temperature (87 atmospheres)—is extremely doubtful. Another objection to all conclusions of the kind above referred to lies in the fact that fluid inclusions are sometimes of secondary origin; and we have, at present, no safe criterion by which we can judge in all cases as to the original or secondary character of any particular inclusion.

VOGELSANG [1] appears to have been the first to doubt the original character of the fluid inclusions of the minerals of eruptive rocks. He calls attention to the fact that they usually lie in planes, which may be regarded as cracks, and he considers them to be "cavities which, in most cases, have not been quite filled up with liquid by secondary injection." This conclusion is confirmed, so far as a particular rock is concerned, by A. A. JULIEN.[2] Fluid inclusions of the normal kind abound in the quartz of the fibrolitic gneiss of New Rochelle. When examined with a high power ($\frac{1}{4}$-in. objective) the rock is seen to be traversed by very numerous and exceedingly minute fissures, partly in planes which are approximately parallel, at least, within the area of the thin section, and partly as branching cracks in an irregular net-work." Needles of fibrolite are scattered throughout the quartz grains in this rock, and where the fissures cross the needles they are represented by minute dark lines. The fluid inclusions are, for the most part, limited to the quartz grains and the planes in which they lie correspond exactly with the cracks in the fibrolite needles. The author's general conclusions are as follow:—"All these phenomena are interesting evidences of the microscopic results of the internal and gradual movements within the mother rock, in the process of folding. The mass has been repeatedly seamed by minute fissures, yielding the plasticity long recognised in rock-masses of apparently the greatest rigidity, and repeatedly re-cemented by siliceous films, deposited out of the concentrated and heated solutions which saturated the rock."

KALKOWSKY [3] has also called attention to the correspondence between the lines of fluid inclusions and cracks in the fibrolite needles in a rock from the Eulengebirge, similar to the one on which JULIEN's observations were based.

Dr. HICKS [4] refers to the probable secondary origin of inclusions in the

(1) Philosophie der Geologie. Bonn, 1867, p. 155.

(2) On the fissure-inclusions in the fibrolitic gneiss of New Rochelle. Amer. Jour. Micro. Sci., 1879.

(3) Die Gneissformation des Eulengebirge. Leipzig, 1878, p. 7.

(4) On Cambrian Conglomerates in Anglesea and Caernarvon. Q.J.G.S., vol. XL., p. 194.

granitoid rocks which he has termed Dimetian. He calls attention to the fact that one and the same plane of inclusions may be traced through two or more grains of quartz; a phenomenon which is entirely inexplicable on the assumption that the inclusions are original.

Professor JUDD [1] argues in favour of the secondary origin of the fluid inclusions in the felspar of the gabbro of the Western Isles of Scotland.

MINERAL INCLUSIONS.—Inclusions of one mineral in another are by no means uncommon amongst the constituents of igneous rocks. Thus, apatite is constantly seen to be enclosed in other minerals. Olivine is frequently enclosed in felspar, hornblende and augite. Augite is sometimes seen to be enclosed in felspar, and sometimes the relation of these two minerals is reversed. Augite is often enclosed in leucite.

In all such cases as those referred to we have direct evidence of the order in which the different constituents of the rock have crystallised. The enclosed mineral is necessarily the earlier of the two. The only exceptions to this rule that can possibly occur are cases in which crystallisation has taken place in a portion of the liquid magma, enclosed in a growing crystal, after the enclosure has been effected. These cases, however, do not present any serious difficulty in actual practice because the enclosed liquid has not a definite composition, and we accordingly find, in addition to the mineral, some other substance; such, for instance, as glass. A study of the phenomena of mineral inclusions shows very clearly that the minerals of igneous rocks do not necessarily separate in the order of their fusibilities; a conclusion long ago arrived at by BUNSEN.[2]

Under the present heading we may refer to those singular inclusions to which PROFESSOR JUDD has recently called special attention, in his paper on the "Tertiary and Older Peridotites of Scotland." [3] In the minerals of certain rocks, especially those which there is reason to believe have consolidated at considerable depths and therefore under great pressure, we find minute rods and plates, often exhibiting a more or less definite external form, arranged in planes which correspond to natural faces, or to well marked structural planes of the crystal itself. Thus, in the felspar of the Gabbro of the Cuchullin Hills, Skye, minute black rods and plates are seen

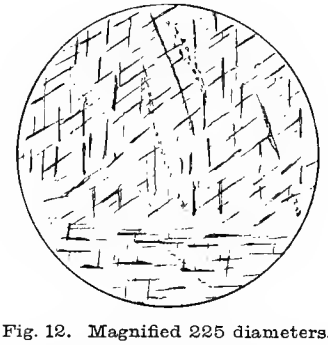


Fig. 12. Magnified 225 diameters.

(1) On the Tertiary and Older Peridotites of Scotland. Q.J.G.S., vol. XLI., p. 375.
(2) Z.D.G.G., vol. XIII., p. 62. 1861
(3) Q.J.G.S., vol. XLI., p. 354.

to occur along one, two, three, four, or even more planes. Where five planes of inclusions occur they correspond to the macropinacoid, the brachypinacoid, the two prism faces, and the basal plane. Sometimes the dimensions of the inclusions are such as to enable them to be observed with low powers; at other times they can only be resolved by the use of the highest powers; and in some cases there is reason to believe that they are ultra-microscopic. The play of colours, so characteristic of the well-known labradorite, from Labrador, is due to the presence of these minute inclusions.

The pyroxenes, both monoclinic and rhombic, sometimes contain inclusions which remind one, so far as their arrangement is concerned, of those of the felspar, already described. (See figs. 13 and 14.)

Fig. 13. Magnified 75 diameters.

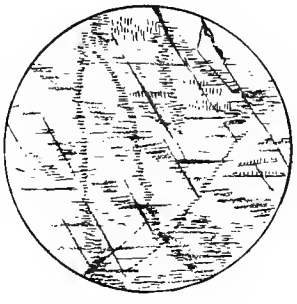


Fig. 14. Magnified 225 diameters.

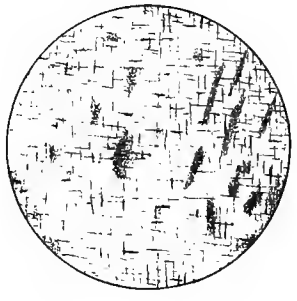


Fig. 13. Inclusions in augite, from olivine-gabbro, Loch Corniskh, Skyo. The inclusions appear to have been developed along lines of cracks.

Fig. 14 Pseudo-hypersthene, from olivine-gabbro, Loch Coruiskh. Two sets of inclusions lying in planes at right angles to each other, are well marked. A third set, probably inclined to the plane of the section, is also distinctly represented.

It is difficult to determine the nature of these inclusions. They are regarded by some observers as crystals of hematite, magnetite, brookite, augite, or other minerals; and by others, including Professor Judd, as mixtures of various oxides, in a more or less hydrated condition; such as hyalite, opal, göthite, and limonite. According to the latter view their definite form is explained by the assumption that they are negative crystals. It is the presence of these inclusions along definite planes which gives the "schiller," or sheen, so characteristic of diallage, pseudo-hypersthene, bronzite, and hypersthene (paulite). In diallage the inclusions are developed along one set of planes, parallel, or approximately parallel, to the ortho-pinacoid. In pseudo-hypersthene (Dana), they are developed along two or more sets. Bronzite and hypersthene proper (paulite) are the "schiller" varieties of the rhombic pyroxenes which correspond respectively to diallage and pseudo-hypersthene of the monoclinic group.

The olivines which occur associated with felspars and pyroxenes having the characters above described also exhibit peculiarities which differentiate them from the olivines of volcanic rocks. They contain peculiar and often

dendritic inclusions of an opaque substance, probably magnetite. These (See Fig. 15 [1]) inclusions lie along the irregular cracks which traverse the

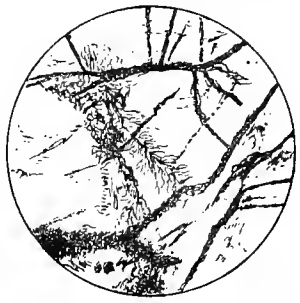


Fig. 15, magnified 100 diameters.— Inclusions in olivine of picrite from Rum.

crystals; and sometimes are so numerous as to destroy the normal appearance of the olivine and render it perfectly opaque.

All these inclusions are regarded by Prof. JUDD as of secondary origin, due to a deep-seated metamorphic process for which he has proposed the term "*schillerization.*" It is not a little interesting to find in minerals of the basic plutonic rocks, so extensively developed on the west coast of Scotland, a set of connected characters, like the above, differentiating them from the corresponding minerals of volcanic rocks.

Schillerized minerals are, however, by no means limited to normal plutonic rocks. They occur in rocks which form an integral portion of the Hebridean gneissic system of the extreme north-west of Scotland.

INTERGROWTHS OF DIFFERENT MINERALS. — In ordinary mineral inclusions there is no definite relation between the enclosed and enclosing crystals. The former are taken up mechanically by the latter during the process of crystal-growth. In certain cases, however, we find that two minerals which have crystallised simultaneously give rise to an aggregate the different parts of which have a more or less definite relation to each other. This is the case for instance in the well known graphic granite and in its microscopic equivalent, generally termed micro-pegmatite. Quartz and felspar have here crystallised simultaneously so that the isolated portions of quartz, which frequently exhibit a triangular outline in section, possess a uniform optic orientation, and therefore extinguish simultaneously as though they were parts of one and the same crystal. When the aggregate shows a tendency to the spherical form we have the structure for which Professor ROSENBUSCH has proposed the term pseudo-spherulite, and which has been also designated "centric structure." Micro-pegmatitic and centric structures are especially characteristic of the granites of St. David's, (Dimetian) and of the Mourne Mounts, Ireland; of the felsite (granophyre) of Carrock Fell; of the augite-granites of the Cheviots; of the granites with augite and hornblende (perhaps secondary) of Charnwood Forest; of the contemporaneous veins and concretionery (?) patches in the bronzite-diabase of Penmænmawr, and many other British rocks.

(1) Figs. 12, 13, 14 and 15 are copied from the plates illustrating Prof. JUDD's paper.

Perthite is an interlaminated aggregate of orthoclase or microcline and albite or oligoclase. The laminæ are parallel to the ortho-pinacoid of the orthoclase, and are therefore seen as fine stripes on the two principal cleavage planes. The microscopic equivalent of perthite, termed microperthite by F. Becke,[1] occurs in certain granulites and gneisses.

"Centric" or pegmatitic structures analogous to those which arise in consequence of intergrowths of quartz and felspar, have been observed by Becke to be produced by the intercrystallisation of garnet and felspar, omphacite and felspar and orthoclase and plagioclase, in augite-gneiss and eklogite. These rocks are of course not known to be igneous, but as the structures resemble those found in igneous rocks, it seems advisable to refer to them in this connection.

Another very interesting case of the definite intergrowth of two distinct minerals is that furnished by the rhombic and monoclinic pyroxenes.[2]

The two minerals occur in lamellæ, and are so arranged that the orthopinacoid of the one lies parallel to the macropinacoid of the other.

Magnetite and ilmenite may also be mentioned as occurring in definite intergrowths.[3]

Augite and hornblende furnish another illustration of the same principle. The interpretation of the structure in this case is, however, complicated by the fact that hornblende frequently arises, as a secondary product, by the alteration of augite; and when this is the case, it is, of course, incorrect to describe the relation as due to the intergrowth of two minerals.

Many other illustrations of the same kind might be mentioned, but the general nature of the subject is sufficiently illustrated by those which have been referred to. On reviewing the facts a conclusion which may prove to be of considerable general interest naturally suggests itself. We know that the most powerful object glasses do not enable us to approach the limits of molecular structure and there is, therefore, no reason to believe that the microscopic limit of visibility corresponds with anything definite in the nature of crystalline growth. It follows then that definite associations of distinct minerals, analogous to those which may be observed both macroscopically and microscopically, may occur also on an ultra-microscopic scale.

Zonal Structure.—A typical crystal is perfectly homogeneous. Each portion of it possesses the same chemical and physical characters as every other portion. In the crystalline constituents of igneous rocks there are, however, important deviations from this rule, in consequence of isomorphous replacements.

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(1) Die Gneissformation des niederöstereicheschen Waldviertels. T.M.M., 1882, p. 199.

(2) O. Trippke. N.J., 1878, p. 673.

E. Cohen, Sammlung von Mikrophographien. Plate LVIII., fig. 2.

Teall. Microscopical and chemical characters of the Whin Sill. Q.J.G.S., vol. XL., p. 650.

(3) Neef. Über seltenere krystallinische Diluvium-Geschiebe der Marke. Z.D.G.G, vol. XXXIV., p. 470.

Küch. Beitrag zur Petrographie des westafrikanischen Schiefergebirges. T.M.M., Vol. VI., 1885, p. 129.

It is a well known fact that we have in the felspars of the plagioclase group a series of forms intermediate between albite and anorthite [1] and that the physical characters, of which the optical are the most important for our present purpose, are definitely related to the chemical so that conclusions as to the latter may be drawn from an examination of the former. Now, in the porphyritic felspars of such rocks as the andesites, we constantly find crystals, built up of successive zones of material, having different optical characters. Thus, in the large felspars of the Cockfield and Ayton Dyke, which must, on the whole, be referred to labradorite, we frequently find an external zone having optical characters more nearly allied to bytownite. [2] Sometimes three or four zones may be observed exhibiting optical characters, which do not indicate a variation in any one definite direction; a zone of material allied to bytownite or anorthite, for instance, may be intercolated between two, having the characters of labradorite. [3]

The observations of HÜPFNER [4] and BECKE [5] appear to lead to the conclusion that in the majority of cases the felspar of the central portion is more basic in composition, that is more allied to anorthite, than that of the exterior. Sometimes the successive zones are divided from each other by tolerably sharp lines, but very commonly there is a perfectly gradual transition. Fig. 16 illustrates this feature.

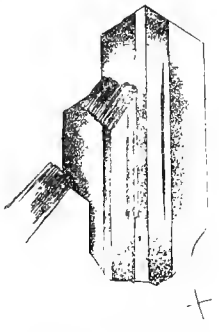

Fig. 16. *(After Becke.)*

The position of the nicols is indicated by the cross. The central portions of the principal individual are light; the corresponding portions of the twin lamellæ are dark. In the exterior portions the relations of the twin lamellæ and principal individual are exactly reversed; and there is a gradual transition from one condition to the other.

Zonal structure is also common in many other minerals especially augite, hornblende, and tourmaline. In the cases of the last-mentioned minerals it is usually indicated by variations in colour.

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(1) Über die optische Orientirung der Plagioclase. Max Schuster T.M.M., 1881, vol. III. p. 117.

(2) TEALL. Notes on some North-of-England Dykes. Q.J.G.S., 1884, p. 217.

(3) M. LÉVY has endeavoured to explain these variations in optical character without assuming variations in chemical composition. Comptes Rendus, 23rd Jan., 1882.

(4) N.J., 1881, Vol. II., p. 183.

(5) T.M.M., Neue Folge, Vol. V., p. 161.

Zonal structure unquestionably indicates changes in the environment of the crystal during the period of growth. The separation of crystals in a magma must necessarily produce a change in the composition of the part which remains liquid, and this cause alone may explain such cases as those observed by HÖPFNER and BECKE. Changes from green to brown, and *vice versâ*, observed in certain hornblendes can probably be explained on the assumption that the growing crystals were alternately subjected to oxidising and reducing agencies. Until we are more fully informed as to the chemical and physical changes which occur during the period of crystal-building in igneous magmas and the effects of such changes on the growing crystals we cannot, however, hope to render a complete account of the various structures observed in the crystalline constituents of igneous rocks.

The curious "hour-glass" structure first described by WERWEKE [1] may here be referred to, though it is not a zonal structure in the proper sense of the term. In the case of an augite possessing this structure a section parallel to the vertical axis, taken in any azimuth, can be separated into four fields in such a manner that the two opposite are alike in colour and optical properties. The two pairs, however, differ from each other to some extent in respect of these properties. Sections through the crystal at right angles to the axis show merely a zonal structure. This curious phenomenon can be explained on the assumption that a skeleton of augite, having an hour-glass form, with the vertical axis corresponding with the length of the hour glass, was first formed and the crystal completed by the filling up of the space between the two bulbs with augite substance of a somewhat different composition.

SPHERULITES.—Crystalline aggregates of a more or less spherical form, and possessing therefore a certain amount of individuality occasionally occur as constituents of igneous rocks. The surfaces of these aggregates are sometimes smooth and sharply defined from the rest of the rock, at other times they are irregular, and the external boundaries are indistinct.

True spherulites, according to ROSENBUSCH, give a black cross, which remains stationary as the stage is rotated under crossed nicols. They are composed of crystalline fibres having each an axis of elasticity coincident with the axis of figure; the separate fibres being arranged in a radial manner round one or more centres. Such spherulites are especially common in glassy rocks having a high percentage of silica. They usually have a smooth surface and are sharply defined from the glass in which they lie embedded.

Spherulitic aggregates, as has been already pointed out, are sometimes formed by the intercrystallisation of two or more minerals. These are termed pseudo-spherulites by ROSENBUSCH. Their optical characters are usually more complicated than those of the true spherulites in consequence of the want of coincidence between the axes of elasticity and the axes of figure in the individual elements. The well known orbicular diorite of Corsica (Napoleonite) may be quoted as an illustration on a large scale of this type of spherulite. In this case the minerals constituting the spherulite are anorthite and hornblende.

Many individual minerals such as epidote, certain zeolites, arragonite, chlorite, &c., tend to form radial or spherulitic aggregates.

(1) Beitrag zur Kenntuiss der Limburgite. N.J., 1879, pp. 482 and 822.

If the mineralogical constituents of igneous rocks be considered from the ætiological point of view they may be classified as follows :—

(1) Those foreign to the rock mass.
(2) Those formed prior to the final consolidation of the rock.
(3) Those formed in connection with final consolidation.
(4) Those formed by secondary actions during or subsequent to consolidation.

It is no part of our present purpose to discuss the origin of igneous magmas. They may be portions of the original fluid material of the earth as some suppose; or they may result from the fusion of sedimentary or other rocks. Our object is to describe and explain, so far as possible, the characters which igneous rocks possess and we take as the starting point for this purpose a mass of molten material. Now igneous rocks occasionally contain minerals and fragments of rocks which have clearly been derived from pre-existing rocks. These are regarded as foreign to the rock-mass in which they occur, although it must be remembered that they may in some cases represent the residue remaining after the fusion of a considerable mass of pre-existing rock.

Minerals of the second and third classes in the above scheme of classification are termed primary. The distinctions between the two classes is most sharply marked in the case of the volcanic rocks with porphyritic texture. The material which issues from a volcano during an eruption is very rarely in a state of true igneous fusion. In the majority of cases it contains crystals and fragments of crystals which have been formed before the lava reaches the surface. Thus, basaltic lavas frequently contain olivine and sometimes also felspar and augite (*e.g.* lavas of Etna); andesitic lavas contain felspar and one or more of the ferro-magnesian minerals such as hornblende, augite, enstatite,[1] or biotite; rhyolitic lavas contain quartz and felspar. These minerals are usually of considerable size and therefore easily recognised by the naked eye after the rock has consolidated. They belong to the second group in the above classification.

As the lava solidifies at the surface a further development of crystals takes place. These are usually smaller in size and frequently require the microscope for their detection. They constitute the groundmass of the rock, and belong to the third group in the above classification.

In the instance referred to, the distinction between the first and second periods of crystallisation is well marked; but this is not always the case. Masses of molten material may consolidate at considerable depths and without any movement occurring after the process of crystal-building has commenced. Consolidation under these circumstances would in general be a slow and gradual process. It would not be interrupted by any abrupt change in the conditions, such as that which takes place when a molten mass is erupted at the surface. Certain granites, diorites and gabbros are supposed to have been formed under

(1) The term enstatite is here used to cover the entire group of rhombic pyroxenes.

such circumstances. In these rocks the porphyritic texture is comparatively rare and the separation of the primary minerals into the two classes above referred to becomes in many cases impossible.

Minerals of the fourth group are termed secondary. They owe their existence to a variety of causes many of which are very imperfectly understood. In the first place we have to notice the fact that it by no means follows that all the minerals which are formed during the process of consolidation result from the direct separation of crystals from the molten magma. In certain cases minerals are produced by the action of the magma on crystals previously formed or on the minerals and fragments which are foreign to the rock mass. The hornblende crystals of certain andesites and porphyrites are often surrounded by a dark border which may be sometimes resolved, by the use of a high power, into an aggregate of magnetite and augite granules. In this case the two latter minerals must be regarded as due to secondary processes operating before the final consolidation of the rock. As an illustration of the development of minerals in consequence of the action of the magma on foreign substances, the very interesting case of the production of bipyramidal quartz-crystals at the zone of contact of a basaltic magma with sandstone and other inclusions, described by J. Lehmann,[1] may be instanced. In this case there can be little doubt that the basaltic magma has taken up silica from the inclusion so that, as cooling progressed, the solution at the zone of contact became supersaturated and a crystallisation of quartz took place.

The secondary minerals, however, owe their origin, as a rule, to agencies which have operated subsequently to the consolidation of the rock. There are for instance the surface agencies which depend largely on the passage of water through the mass of the rock and give rise to the formation of such minerals as chlorite, epidote, serpentine, carbonates and zeolites; there are deep-seated agencies which depend on the action of water, acid gases and other substances at a high temperature and under great pressure; and lastly, there are the mechanical agencies which produce the phenomena of regional metamorphism. By the operation of one or more of these agencies igneous rocks may be more or less modified, and in some districts every gradation may be found from a rock possessing all its original characters to one in which there has been a complete molecular re-adjustment and a destruction of all the original textural characteristics. A massive dolerite (diabase), for instance, may be converted into a chloritic-[2] or hornblendic-schist.[3]

(1) Die pyrogenen Quarze in der Laven des Niederrheins. Verh. d. naturh. Vereins. Bonn 1877.

(2) Lossen. Studien an metamorphischen Eruptiv-. und Sedimentgesteinen. Jahr. d. k. Preuss. Geol. Landesanstalt. Berlin, 1884. p. 628.

(3) Teall. Metamorphosis of dolerite into hornblende-schist. Q J.G.S. Vol. XLI. p. 133.

List of Minerals occurring as constituents of Igneous Rocks.[1]

ORIGINAL MINERALS.

Allanite
Amphibole-group
- Hornblende
- Arfvedsonite

Apatite
Chromite
Cordierite
Eudialyt
Garnet group
- Melanite
- Pyrope

Hematite
Ilmenite
Leucite
Magnetite
Mica-group
- Biotite
- Lepidolite
- Muscovite
- Rubellan

Monoclinic felspars
- Orthoclase
- Sanidine

Monoclinic pyroxenes
- Aegirin
- Augite
- Diallage
- Diopside

Nepheline (Elœolite)
Nickel-iron
Olivine
Perowskite
Quartz
Rhombic pyroxenes
- Enstatite
- Bronzite
- Hypensthene

Rutile
Skapolite
Sodalite-group
- Sodalite
- Hauyn (Nosean)

Sphene
Spinelle-group
- Pleonaste
- Picotite

Topax
Tourmaline
Tridymite
Triclinic felspars
- Microcline
- Anorthoclase [2]
- Albite
- Oligoclase
- Andesine
- Labradorite
- Bytownite
- Anorthite

Zircon
&c., &c.

SECONDARY MINERALS.

Albite[3]
Amphibole group
- Tremolite
- Actinolite
- Hornblende
- Uralite

Analcime
Anatase
Anthophyllite
Arragonite
Axinite
Bastite
Brookite
Calcite
Chalcedony
Chlorite-group
Corundum
Delessite
Dolomite
Epidote
Fluorite
Garnet
Hematite
Kaolin
Magnetite
Muscovite
- (Sericite)

Opal
Pyrite
Pyrrhotite
Quartz
Rutile
Serpentine
Scapolite
Siderite
Talc
Tridymite
Wollastonite
Zoisite
&c., &c.

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(1) It does not fall within the scope of the present work to describe in detail the chemical and physical characters of the rock-forming minerals. For information on this subject the reader is referred to treatises on mineralogy and to one or more of the following works.

Fouqué and Lévy. Mineralogie Micrographique. Paris, 1879.

Rosenbusch. Mikroskopische Physiographie der Petrographisch wichtigen Mineralien, 2nd Edit. Stuttgart, 1885.

Hussak. Einleitung zum Bestimmen der Gesteinsbildenden Mineralien. Leipzig, 1885.

(2) Rosenbusch proposes this term for certain potash-soda felspars (isomorphous mixtures of orthoclase and albite with or without anorthite), which have been examined and described by Klein (Über die Felspath im Basalt vom Hohen Hagen. Göttingen Nachrichten, 1878, No. 14), Brögger (Die Silurishen Etagen 2 und 3. Kristiania, 1882, pp. 260 and 293) and Förstner (Über die Felspäthe vom Pantellaria (Z.K., 1883, VIII. p. 125).

(4) And probably also other felspars.

CHAPTER II.

The Chemical Characters of Igneous Rocks

An igneous rock is not a definite chemical compound. If we except the comparatively rare case in which it takes the form of glass, it is an aggregate of one or more definite compounds (minerals) with or without an amorphous base. The chemical elements which make up the bulk of igneous rocks are oxygen, silicon, aluminium, iron, calcium, magnesium, potassium and sodium. If, however, we consider those which occur in smaller quantities, or as traces, then it is possible that every known element may be represented in igneous rocks. Titanium, phosphorous and manganese, are frequently present in sufficient quantity to be estimated in small portions of the rock. Barium, strontium and lithium may often be detected; cæsium and rubidium occur in leucite. Zirconium occurs in the widely distributed mineral zircon; cerium and lanthanum are found in allanite,[1] a mineral recently detected in many igneous rocks. Chromium occurs as a constituent of the minerals picotite, chromite and certain diopsides. Hydrogen is present in water, an original constituent of certain igneous rocks. Carbon in carbonates; sulphur in sulphates, pyrites, and in the original minerals, hauyn and nosean. Chlorine is present in sodalite, and in the chlorides which occur in the liquid inclusions in many granitic rocks. Boron and fluorine are found in tourmaline, and the former element has recently been detected in many micas.

The researches of F. Sandberger[2] have added enormously to the list of elements which must be regarded as occurring in normal igneous rocks. This author has shown that if a sufficient quantity, say from ten to twenty grammes, of the common rock-forming minerals, mica, olivine, augite and hornblende, be taken, it is possible to detect many of the metals which are usually known only as constituents of mineral veins. Thus copper, nickel and cobalt were constantly found to be present in olivine. Tin and arsenic were found only in this mineral from certain localities, and always in very small quantities. Copper and cobalt were constantly found in the augite of gabbro, diabase, melaphyre, augite-porphyrite, augite-andesite and basalt. Nickel, lead, tin, zinc, antimony and arsenic were found only in the augites of certain localities. Hornblende from the older rocks was found to contain nickel, copper, arsenic and cobalt; that from the younger rocks yielded the same elements, and in addition lead, antimony, zinc and bismuth. The minerals of the mica group

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(1) Iddings and W. Cross. Occurrence of allanite as a constituent of many rocks. A.J.S., Vol. XXX., p. 108.

(2) Untersuchungen über Erzgänge. 1st Part, 1882. 2nd Part, 1885. Wiesbaden.

were found to be the richest in the heavy metals, and to contain the greatest variety. Lithia-micas (lepidolite, zinnwaldite and the dark-coloured rabenglimmer of Breithaupt) always contained tin, and with the exception of lepidolite, arsenic, copper and bismuth ; many of them contained also uranium. Potash micas were found to be poor in the heavy metals, copper being the only one which was commonly present. Arsenic, lead, zinc, copper, antimony, cobalt, nickel and silver were detected in the black micas of certain granites and gneisses. The black mica of the so-called propylite of Schemnitz was proved to be especially rich in arsenic, lead and zinc ; and it contained also copper, cobalt and antimony. The rubellan of certain basalts contained antimony, lead, copper and cobalt in considerable quantities, and traces also of bismuth. BECKER [1] has proved the existence of silver and gold in the unaltered augite of the igneous rocks in which the Comstock lode is situated.

These observations show that the so-called rare metals are very widely distributed, and that they can only be said to be rare in the sense that they are not present, as a rule, in sufficient quantity to be detected by the ordinary methods of analysis. The importance of this fact with reference to the origin of mineral veins is obvious.[2]

As a rule the chemical elements are not found in igneous rocks in the uncombined state. They usually form complex chemical compounds of which the silicates are by far the most important. Native iron has, however, been detected in the basalts of the north of Ireland by Dr. ANDREWS [3]; and it occurs in large and small masses, alloyed with nickel and cobalt, in similar rocks from the west of Greenland.[4]

In discussing the chemical characters of igneous rocks in greater detail it will be convenient to use the old chemical nomenclature, and speak of them as composed of the oxides; silica, alumina, lime, magnesia, &c. Chemical analyses are always expressed in accordance with this nomenclature. Consider now the distribution of the different constituents in the different varieties of unaltered igneous rocks.

Silica varies from about 40 p.c. in certain olivine rocks (dunite) to about 80 p.c. in certain liparites or rhyolites. If the analyses of a large number of igneous rocks be compared it will be seen that they may be arranged in a continuous series, so that the silica percentage varies gradually and continuously from one extreme to the other. Variation in silica-percentage is accompanied by variation in the other chemical and physical properties.

Alumina varies within much narrower limits, viz., from almost nothing to about 20 p.c., if we include the olivine rocks; and from about 10 to 20 p.c. if we exclude these rocks.

Ferric oxide, ferrous oxide, magnesia and lime exhibit wide divergencies in their relative proportions—divergencies which must be explained by local

(1) Geology of the Comstock Lode, U.S. Geological Survey. Monographs, Vol. III.

(2) The above account of elements already recognised as occurring in igneous rocks does not profess to be exhaustive.

(3) British Association Report, 185, (pt. 2), p. 34.

(4) STEENSTRUP. On the existence of Nickel-iron with WIDMANSTÄTTEN'S figures, in the basalt of North Greenland. M.M., Vol. VI., page 1.

rather than general causes; but taken as a whole they may be said to vary inversely as the silica. In the most siliceous rocks they make up only 4 or 5 p.c. of the mass; in the least siliceous they sometimes form as much as 40 or even 50 p.c.

The alkalies, potash and soda, present very interesting relations. If we except the leucite-, nepheline- and hauyn-bearing rocks, which are somewhat limited in their range in space and time, and which, taken together, appear to be insignificant in bulk when compared with all the other igneous rocks, then we may state that, as a general rule, the total alkalies increase with the silica-percentage, and the relations of the two alkalies, potash and soda, become reversed; soda is the dominating alkali in the basic, potash in the acid rocks. It must be understood that this law is true only in a broad and general sense, especially as regards the relations of the two alkalies. In rocks of the intermediate class, the andesites and porphyrites and their granular representatives, the more acid dolerites (diabases) and diorites, the mutual relations of the two dominant alkalies often cease to have any very definite relation to the silica-percentage.

The leucite-, nepheline- and hauyn-bearing rocks, represented in England so far as we know at present by the solitary example of the phonolite of the Wolf Rock, are characterised by an abnormally high percentage of alkalies. They are extensively developed in certain parts of the continent of Europe, in some of the volcanic islands of the Atlantic, and sparsely in North America. They have been recorded also from the north of Africa, Persia and the Sandwich Islands. It is worthy of note that where they bulk most largely the normal igneous rocks, the andesites, basalts and rhyolites, are not very extensively developed; and that where the latter occur in great abundance the former are rare or altogether absent. In the Schemnitz district of Hungary,[1] for example, andesites are developed on an enormous scale, and basalts and rhyolites to a considerable extent. Leucite-, nepheline- and hauyn-bearing rocks are conspicuous by their absence. In the tertiary volcanic district of Bohemia this condition of things is reversed. If we take a general view of the igneous products of all geological periods and of all countries it seems impossible to avoid the conclusion that the leucite-, nepheline- and hauyn-bearing rocks are separated from the great bulk of igneous products by peculiarities in their distribution both in space and time, as well as by peculiarities in chemical and mineralogical composition.

In preparing material for a bulk-analysis of any igneous rock care must be taken to select a sufficient quantity to give a satisfactory average. In the case of coarse-grained rocks it is necessary to take a very much larger quantity than is actually required for analysis. Attention should also be paid to any variations which may occur in the composition of the rock-mass. Plutonic rocks often show a considerable amount of variability in the mineralogical and chemical composition of different portions of the same rock-mass. Patches often occur which contain the same minerals as the main mass of the rock, but

(1) Judd.—On the ancient volcano of the district of Schemnitz. Q.J.G.S., Vol. XXXII., p. 292.

in different proportions.[1] The origin of these patches cannot be explained in all cases; sometimes they may indicate an imperfect mixing of the original constituents of the rock—a want of homogeneity in the original magma; at other times they may be due to the metamorphism of included fragments of foreign rocks, and their injection by the igneous magma; and at others to a separation of the minerals first formed by gravity or other causes.

Any want of homogeneity in the original magma must of course tend to produce a want of homogeneity in the volcanic rocks produced by its eruption at the earth's surface in the form of lava. The differential motion of the lava will tend to drag out any parts of exceptional composition into the form of streaks or elongated lenticles (schliere).[2] We accordingly find that a certain want of uniformity is a common characteristic of many volcanic products; especially those which are rich in silica.

The bulk-analysis of an igneous rock may be regarded from two points of view: it may be considered with reference to the analyses of the individual constituents of the rock itself, or with reference to the bulk-analyses of other rocks. In discussing the analyses of rocks and minerals, the oxygen-ratio (quantivalent ratio of modern chemistry) and oxygen-quotient are of considerable utility. For the purpose of ascertaining the oxygen-ratio, the constituents are divided into three classes, in consequence of the fact that the members of these classes are capable of replacing each other to a certain extent in the rock-forming minerals without affecting the crystalline form. Silica and titanic acid belong to the first class; alumina and ferric oxide (the sesquioxides) to the second; and the remaining constituents (the monoxides), lime, magnesia, ferrous oxide, and the alkalies, to the third. The symbol $\bar{R}$ stands for a double molecule of one of the metallic elements in a sesquioxide base (*i.e.*, for Al_2, Fe_2, or Cr_2), and R for a molecule of a metallic element in one of the monoxide bases. R may therefore represent a molecule of a dyad element, such as calcium, magnesium, or ferrous iron; or that of a monad element, such as potassium, sodium, or lithium. It is sometimes convenient to indicate the valency of the element for which R stands, by a sign over the R, thus: $\overset{I}{R}$ represents a monad element, such as one of the alkalies; $\overset{II}{R}$ a dyad element, such as calcium or magnesium. Adopting these symbols, the common bases of the minerals of igneous rocks may be expressed as follows:—$\overset{VI}{\bar{R}}O$, $\overset{II}{R}O$, and $\overset{I}{R}^2O$. In determining the oxygen-ratio, $\overset{II}{R}O$ and $\overset{I}{R}O$ are usually taken together. This ratio is the ratio of the amount of oxygen combined with the silicon to that combined with the elements represented by $\bar{R}$, to that combined with the elements represented by R. Thus, in the following analysis of granite, by Dr. Haughton, we have—

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(2) Phillips, J. A., On concretionary patches and fragments of other rocks contained in Granite. Q.J.G.S., Vol. XXXVI., p. 1.

(2) Reyer, E. Vulkanologische Studien. Jahr. d. geol. Reichsanstalt. Vol. XXVIII., p. 81. Vienna.

Die Euganeen. Wien, 1877, p. 69, and Vol. XXVIII., p. 216.

SiO_2	72·24	Oxygen =	37·51	
Al_2O_3	14·92			
Fe_2O_3	1·63	,, ...	7·46	
Fe O	·23			
Mn O	·32			
Ca O	1·68			
Mg O	·36	,, ...	2·50	
K_2O	5·10			
Na_2O	3.51			

Oxygen ratio = 37·51 : 7·46 : 2·50
or = 15 : 2·9 : 1

The oxygen quotient in this case $= \frac{7{\cdot}46 + 2{\cdot}50}{37{\cdot}51} = {\cdot}265.$

Now, of all the common rock-forming silicates, orthoclase and albite contain the highest proportion of silica. The oxygen-ratio in both these minerals is 12 : 3 : 1, and the oxygen-quotient is ·333. Any rock, therefore, which has a lower oxygen-quotient than this must contain free silica. Any rock which has a higher oxygen-quotient may or may not contain free silica. An examination of the elaborate tables of rock analyses compiled by J. Roth[1] will show that the oxygen-quotient of igneous rocks varies from about ·2 in the case of obsidians and liparites (rhyolites) to about ·8 or ·9 in the case of the olivine-rocks.

Under certain circumstances, when the oxygen-ratios of the entire rock and of the individual constituents are known, the percentage composition of the rock in minerals may be calculated.[2]

Thus the composition of the Donegal granite above referred to is—

Quartz	30·63 per cent.
Orthoclase	24·33 ,,
Oligoclase	41·88 ,,
Biotite	3·16 ,,

Although there is, of course, a close connection between the composition of the rock as a whole and that of the minerals which enter into its composition, this connection is not so close as might at first sight be supposed. Rocks of diverse chemical composition are often composed of the same minerals, and rocks composed of the same minerals often differ considerably in chemical composition. Observation and experiment show that the mineralogical composition of a rock is determined by two factors: (1) the chemical composition of the magma and (2) the physical conditions under which the individualisation of definite chemical compounds has been effected. Thus; if hornblende, having a certain chemical composition, be reduced to a perfectly molten state by intense heat and then allowed to cool it will, under certain

(1) Beiträge zur Petrographie der plutonischen Gesteien.

(2) For particulars as to this method, see Dr. Haughton's paper on "Irish Granites." Q.J.G.S., vol. XVIII., 1862.

conditions, consolidate as a crystalline mass almost entirely composed of augite; but if it be maintained at a very high temperature during the initial stages of consolidation and then allowed to cool somewhat more rapidly both olivine and augite will be formed.[1] In this case we see that the development of olivine is dependent on the physical conditions of consolidation. The researches of Messrs. Fouqué and Lévy[2] on the artificial production of rocks and minerals may also be referred to for illustrations of the effect of physical conditions in determining the mineralogical characters of rocks.

One of the most interesting constituents of certain volcanic rocks is the glassy or crypto-crystalline matter in which the crystalline constituents are embedded. In many cases this may certainly be regarded as representing the mother-liquor remaining after the separation of the crystalline constituents from a magma having the same composition as the entire rock A comparison, therefore, of the analysis of this interstitial matter with the bulk-analysis of the rock will throw light on the changes which occur in the liquid magma in consequence of the successive formation of crystals. It is unfortunate that we do not possess at present a large number of analyses available for the purpose of instituting such a comparison; nevertheless, those which we have are sufficient to suggest general conclusions of considerable interest.

	I.	Ia.	II.	IIa.
SiO_2	58·07	70·76	61·17	66·25
TiO_2	—	—	—	—
Al_2O_3	13·22	10·93	16·87	13·59
Fe_2O_3, FeO	10·10	3·59	2·10, 2·94	3·11
CaO	7·04	3·29	4·86	2·75
MgO	4·46	4·21	3·00	·28
K_2O	1·58	7·22	1·81	4 95
Na_2O	2·59		2 67	2·25
H_2O	1·50	—	3·09	5·89
	98·56	100·00	98·51	99·08
Sp. Gr.	2·77	—	2·543	2·437

(1) Becker, A. Schmeltzversuche mit Pyroxenen und Amphibolen. Z.D.G.G. Band XXXVII. 1885, p. 10.

(2) Synthèse des mineraux et des roches. Paris, 1882.

	IIB.	III.	IIIA.	IV.	IVA.
SiO_2	65·16	62·00	69·94	69·36	76·75
TiO_2	—	0·17	—	—	—
Al_2O_3	17·49	17·84	15·63	16·23	12·32
Fe_2O_3 / FeO	3·01	4·40	1·89	0·88 / 1·53	1·36
CaO	0·84	5·37	2·49	3·17	1·18
MgO	2·34	2·64	0·28	1·34	—
K_2O	5·54	1·47	2·85	3·02	3·98
Na_2O	3·68	4·29	3·83	4·06	3·55
H_2O	1·76	1·66 (Ig.)	3·25	0·45	0·54
	99·82	99·84	100·16	100·04	99·68
Sp. Gr.	2·640	—	—	—	—

I. Augite-andesite.[1] Armathwaite Dyke, Cumberland.
IA. Glassy base of same rock.
II. Hypersthene-andesite.[2] Carhope. Cheviot District.
IIA. Glassy base of same.
IIB. Devitrified base of hypersthene-andesite from Allerhope Burn, Cheviot District.
III. Hypersthene-andesite. Mount Shasta, California.[3]
IIIA. Glassy base of same.
IV. Dacite. Lassen's Peak, California.
IVA. Glassy base of same.

A comparison of these analyses leads to the conclusion that the effect of crystallisation in an igneous magma of andesitic composition is to increase the percentages of silica and alkalies, and to diminish those of the other constituents, in the part remaining liquid. Moreover, the effects as regards the alkalies is to increase the potash relatively to the soda; so that in certain cases the relations of the two alkalies become reversed; soda being the dominant alkali in the rock, and potash in the glassy residuum. The general conclusions here reached by purely chemical considerations agree with those deduced from an examination of the order of crystallisation of the different rock-forming constituents as determined by the study of thin sections under the microscope. [4]

Various attempts have been made to express the facts known with regard to the composition of the different kinds of igneous rock in terms of some

(1) TEALL. Petrological Notes on some North-of-England Dykes. Q.J.G.S., 1884, p. 224.

(2) PETERSEN, J. Untersuchungen am Enstatite-porphyrit aus den Cheviot Hills. Inaug. Diss. Kiel, 1884.

(3) HAGUE & IDDINGS. Notes on the Volcanoes of Northern California, &c. A.J.S., vol. XXVI., p. 222.

(4) ROSENBUSCH. N.J., 1882, Band II., p. 1. See also TEALL. G. M. Decade III., vol. II., p. 118.

general law. In 1851 BUNSEN pointed out that[1] the varying composition of a large series of igneous rocks which he had examined from different parts of the world could be expressed with a very considerable amount of accuracy on the assumption that they were due to the mixture, in varying proportions, of two distinct magmas, which he designated by the terms *normal-trachytic* and *normal-pyroxenic*. STRENG, TRIBOLET and others immediately applied the ideas of BUNSEN to the igneous products of the districts with which they were severally acquainted.

In 1857 DUROCHER published his "Essai de Pétrologie Comparée,"[2] in which he propounded the theory that the igneous products of all ages have been derived from "two magmas which co-exist beneath the solid crust of the globe and occupy there each a definite position." The terms acid and basic were given to these two magmas, and their average compositions were supposed to be as follows:—

	ACID.	*BASIC.*
SiO_2	71·0	51·5
Al_2O_3	16·0	16·0
FeO	2·5	13·0
CaO	1·0	8·0
MgO	1·0	6·0
K_2O	4·5	1·0
Na_2O	2·5	3·0
Sp. Gr. of crystalline rock ...	2·65	2·95
Sp. Gr. of glass	2·40	2·72

The majority of the igneous rocks, according to the author, belong to one or other of these types. Rocks of intermediate composition, such as the andesites and porphyrites, are supposed to be due to the intermixture of the two magmas at the zone of contact. Certain rocks of exceptional composition, such as the phonolites, are regarded as due to a process of liquation analogous to that which goes on under certain circumstances in molten metallic mixtures, and which is utilized, for example, in the Pattinson process for separating silver and lead.

The theory of DUROCHER, in so far as it is an expression of the facts known with reference to the composition of igneous rocks, is substantially identical with that of BUNSEN, and may be regarded simply as an extension of the latter with slight modifications; but in so far as it deals with the physical condition of the planet it is peculiar. We are not, however, concerned with the latter aspect of the theory.

VON COTTA[3] adopts a division of the igneous rocks into two principal groups which agree substantially with those of BUNSEN and DUROCHER. He

(1) P. A. LXXXIII., p. 197.

(2) A translation of this Essay is given in Dr. HAUGHTON'S Manual of Geology.

(3) Rocks Classified and Described. Translation by Lawrence, 1866.

points out, however, that there are many intermediate forms; and that the members of the individual groups exhibit a considerable amount of variability.

In reviewing this subject from our present standpoint we are led to the conclusion that the variations in composition in the greater number of igneous rocks, although not capable of being reduced to any very precise law, may be expressed in a broad and general way by the method of BUNSEN. Thus, we recognise two extreme types; the one characterised by a low percentage of silica, high percentages of lime, iron and magnesia; a low percentage of alkalies, and an excess of soda over potash; the other by a high percentage of silica, low percentages of lime, iron and magnesia; a high percentage of alkalies, and an excess of potash over soda. Between these two extreme types we have every possible gradation, and there seems no reason for believing that the extreme types are more abundantly developed than the intermediate forms. As stated in this general manner, and without any attempt to give it numerical precision, the above principle will be referred to as the law of BUNSEN.

It will be seen, on reflection, that a very interesting relation exists between BUNSEN's law and the law which expresses the effect of crystallisation in modifying the composition of an igneous magma. If, after crystallisation has progressed to a certain extent in a magma of andesitic composition, we separate the crystals from the part remaining liquid, the former taken together will have the composition of a basic, the latter of an acid rock. It is scarcely possible that this connection can be the result of chance; and, if not, it seems to suggest that those variations in the composition of igneous rocks which are expressed by BUNSEN's law may be due to differentiation produced in an originally homogeneous magma in consequence of progressive crystallisation.

The leucite- hauyn- and nepheline-bearing rocks furnish important exceptions to the law above referred to, and must be regarded rather as forming a group apart from the other igneous rocks, so far as it is concerned. It is to the basalts, andesites, and rhyolites and their plutonic representatives that the law is especially applicable; but even in these cases it fails when applied to the minute variations which occur in their composition. The exact composition of any igneous rock is doubtless determined by many causes, some of which are general, and others probably local. As the science of petrography advances we may reasonably anticipate that these causes will be brought to light, and the enormous mass of disconnected facts, so industriously collected together and admirably expressed in ROTH's Gesteinsanalysen and his Beiträge zur Petrographie der plutonischen Gesteinen, reduced to something like definite order. At present BUNSEN's law is the only one which seriously claims our attention.

So far reference has only been made to the chemical characters of unaltered igneous products. The chemical composition of altered rocks throws a considerable amount of light on the nature and extent of the alterations to which they have been subjected. Many rocks may now be said to be the pseudomorphs of the original rocks which they represent. The chemical alteration of igneous rocks results in the addition and subtraction

of certain constituents. Thus, the action of water charged with carbonic acid and oxygen gives rise, in many cases, to the decomposition of the original silicates, and the removal of certain constituents. The action is best illustrated in the basic group of rocks. The first stage appears to consist in the formation of carbonates, and the liberation of a certain amount of silica which may or may not be removed in solution. A basic rock in this stage of alteration will frequently effervesce under the action of an acid almost as readily as a limestone. The next stage consists in the removal of the protoxide bases—lime, magnesia and iron—in the form of soluble bicarbonates. If this solution be subjected at any point to oxidising influences the iron is precipitated as hydrous ferric oxide; but if not it may be totally removed from the rock along with the other constituents, and thus give rise to the chalybeate springs. The final result of this alteration is the formation of a loose powdery substance mainly composed of hydrated silicate of alumina, in which however, a large part of the original soda is often retained. The process above described may of course be considerably varied in certain circumstances. Thus, if pyrites be present the oxidation of this substance will give rise to sulphuric acid, which is a powerful solvent, and may even remove a portion of the original alumina as a sulphate. Under other circumstances the lime may be wholly and the iron partially removed, while the magnesia remains behind as a hydrous silicate in the form of serpentine. The general effect of the simple alteration of igneous rocks by surface agencies may be described as the removal of some of the bases, and a certain amount of the silica originally combined with these bases, and the addition of water and oxygen. Some details as to the nature of the chemical alteration to which rocks are subjected will be given when the individual rocks are described.

CHAPTER III.

Physical Characters of Igneous Rocks.

THE most important characters to which reference will be made in the present chapter are specific gravity and texture. Fracture, colour, and hardness, though of less importance, are often of considerable use as furnishing diagnostic characters, and some account of them will therefore be given.

The methods by which specific gravity may be determined are described in the ordinary text-books of physics, and need not, therefore, be explained on the present occasion. In the case of a rock containing no hollow spaces of any kind the specific gravity of any specimen, sufficiently large to represent a fair average sample of the rock, may be determined by the ordinary methods of weighing in air and in water. When hollow spaces are present, it must be broken up into fragments so small as to leave no cavities completely enclosed, and the determination must be made by means of the specific gravity bottle. In using this method care must be taken not to reduce the rock to the condition of too fine a powder, otherwise the result obtained will be somewhat too high. Various methods have been devised for the rapid determination of the specific gravity of rocks, particulars of which together with a discussion of their relative merits, will be found in a paper by Professor Judd, published in the "Proceedings of the Geologists' Association."[1]

The heavy solutions of bi-iodide of mercury and potassium[2] or barium[3] and boro-tungstate of cadmium[4] are of great use for the determination of the specific gravity of small particles. A solution is obtained, by suitable dilution, in which the particle remains suspended, and then the specific gravity of this solution is determined either by using a flask of known capacity (25 c.c.s. is a convenient size) and weight; or else by means of a special apparatus such as that constructed by G. Westphal, of Celle.[5] An ingenious and original method of determining the specific gravity of small particles by the use of the heavy solutions has been devised by Professor Sollas, particulars of which will be found in the "Scientific Proceedings of the Royal Dublin Society" for January 19th, 1885.

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(1) Vol. VIII., 1884, p. 277.

(2) Goldschmidt. N.J., 1881. Beilage, Band I., p. 179. Maximum specific gravity = 3 196.

(3) Rohrbach. N.J., 1883. Band II., p. 186. Max. Sp. Gr. = 3·588.

(4) D. Klein, B.S.M., 1884, p. 149. Max. Sp. Gr. = 3·6.

(5) For description of this apparatus, see N.J., 1883 Band II., p. 87.

In determining specific gravity, it must be remembered that different portions of one and the same rock-mass will often yield different results. In some cases the differences are slight; in others they are considerable. As a general rule the range of variability appears to be greater in plutonic than in volcanic masses. The Cleveland, Cockfield and Armathwaite dyke may be quoted as an illustration of an igneous mass which exhibits a somewhat striking uniformity in specific gravity over great distances. This dyke can be traced at intervals from Maybecks, near Whitby, to Armathwaite in the Eden Valley: a distance of 90 miles. The specific gravities of many specimens of the unaltered rock taken from widely-separated localities were found to lie between 2·765 and 2·788. No other dyke in the North of England was found to possess an average specific gravity lying between these limits. As might naturally be expected, a constancy in the specific gravity of any igneous mass goes along with a constancy in the other chemical and physical properties.

The relation between the specific gravity of a rock and the specific gravities of the constituents of which it is composed may be expressed as follows:—Let A, B, C, &c., represent the proportions by weight of the individual constituents, so that A + B + C, &c., = 100, and let a, b, c, &c., represent the specific gravities of the individual constituents. Then the specific gravity of the rock as a whole will be $\frac{100}{\frac{A}{a}+\frac{B}{b}+\frac{C}{c}\ \&c.}$. In the case of a rock composed only of two constituents, having different specific gravities, the relative proportions of the two constituents may be roughly determined when the specific gravity of the rock as a whole is known, and that of each of the constituents.

The principal interest which attaches to specific gravity, so far as igneous rocks are concerned, lies in the fact that it stands in close relation to the other properties, both chemical and physical. If we compare rocks in the same physical condition, then the specific gravity is seen to vary with the chemical composition in a tolerably definite manner. If, on the other hand, we compare rocks of the same composition, then the specific gravity is seen to depend on the physical condition. In the previous chapter it has been shown that the variations in the chemical composition of igneous rocks are expressed in a broad and general way by Bunsen's law; so that the percentage of any one of the variable constituents gives a certain amount of information with regard to the relative proportions of the remaining constituents. Of the variable constituents silica is unquestionably the one which throws the greatest amount of light on the composition of the rock as a whole. The following table illustrates the general laws with regard to the variations in the specific gravities of the different kinds of igneous rocks.

PLUTONIC ROCKS.[1]

	Mean Sp. Gr.	Extremes of Sp. Gr.	Mean SiO_2 Percentage.	Extremes of SiO_2 Percentage.
Granites (23)	2·65	2·48—2·73	71·64	77·65—62·09
Syenites (10)	2·82	2·73—2·86	63·85	72·20—54·65
Gabbros (13)	2·90	2·82—3·02	51·49	56·46—48·29
Peridotites (5)	3·26	3·22—3·29	44·58	50·59—42·70

VOLCANIC ROCKS.

CRYSTALLINE OR SEMI-CRYSTALLINE.

Felsites and Liparites (38) ...	2·61	2·53—2·70	72·25	76·06—67.61
Porphyrites and Andesites (23) ...	2·66	2·54—2·79	59·20	66·75—54·73
Basalts (23)	2·86	2·75—3·10	48·36	53·73—42·65

VITREOUS.

Liparite-glass (11)	2·36	2·26—2·41	73·80	82·80—71·19
Andesite-glass				
Basalt-glass (9)	2·71	2·69—2·76	52·32	54·93—50·82

An examination of this table suggests the following conclusions:—

The specific gravity decreases as the silica-percentage increases.

The specific gravity decreases as the total amount of glass entering into the composition of the rock increases.

It must be remembered, however, that the law connecting specific gravity and silica-percentage is only true in a broad and general sense. It fails when applied to minute differences and to individual cases, although it stands out strongly when averages are taken. Deviations from the law are due partly to the fact that the silica-percentage does not govern absolutely the relative proportions of the other constituents, and partly to the fact that rocks having the same chemical composition frequently differ in mineralogical composition.

It is interesting to compare terrestrial with extra-terrestrial rocks (meteorites) so far as specific gravity is concerned. For this purpose meteorites may be conveniently divided into four groups.

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(1) This table has been compiled by taking a number of cases at random from "Roth's Beiträge sur Petrographie der plutonischen Gesteine." The number taken in each case is indicated by the figures in brackets.

1st, *Basaltic metorites.* These are somewhat related to basalt in composition. The typical forms consist of felspar (usually anorthite), pyroxene (augite, diallage, enstatite, &c.), and iron ores.

2nd, *Meteoric peridotites.* These are mainly composed of olivine and minerals of the enstatite group. They contain also chromite and picotite. In mineralogical and chemical composition they bear the closest relation to terrestrial peridotites, but they differ in texture.

3rd, *Olivine-iron meteorites.* These consist of metallic iron together with minerals found in the preceding group and others, such as schreibersite, troilite and pyrrhotite, which are especially characteristic of the succeeding group. The iron contains varying proportions of nickel and cobalt.

4th, *Metallic meteorites.* These consist mainly of iron, alloyed with nickel and cobalt. They contain also schreibersite, troilite, pyrrhotite and graphite.

The different groups are not separated from each other by hard and fast lines. The first passes into the second by the decrease of the felspathic constituents and the increase of the magnesian silicates; the second into the third by the gradual introduction of metallic iron; the third into the fourth by the disappearance of the magnesian silicates.

If now we arrange the terrestrial and extra-terrestrial rocks in parallel columns, after the manner of DAUBRÉE, [1] we obtain the following result:—

Felspathic meteorites	3—3·5
Meteoric peridotites...	3·5—3·8
Iron-olivine meteorites	5·46—7.29
Metallic meteorites ...	6·24—7·95

	Sp. Gr.
Stratified rocks	2·6
Granites and felsites ...	2·65
Basalt and Gabbros ...	2·9
Peridotites	3·26

Is it possible, as DAUBRÉE has suggested, that we may by this means obtain an idea of the composition and structure of the interior of the earth?

The connection between terrestrial and extra-terrestrial rocks becomes still closer if we include with the former the metallic nickel-iron [2] which occurs in large and small masses in certain Greenland basalts.

Mr. HILL [3] has recently endeavoured to determine the average density of a mass composed of all the known meteorites. The data available are, as he points out, very imperfect, but the conclusion at which he arrives is, nevertheless, very suggestive. It is, "that an assemblage of such meteoric masses as fall upon the earth, if collected from space indiscriminately and

(1) Géologie expérimentale, 1879, p. 545.

(2) STEENSTRUP.—M. M. Vol. VI., 1884, p. 1. JUDD.—Volcanoes, 1881, p. 319.

(3) On the average density of meteorites compared with that of the earth. G.M., Decade III., vol. II., p. 517.

aggregated into a single mass, would form a body whose specific gravity would probably lie between 4·5 and 5·7, so long as its dimensions were moderate." The most reliable estimate of the average specific gravity of the earth is 5·6, and it is thus seen that there is a very close agreement between the specific gravity of the earth, regarded as a whole, and that of the ideal meteoric mass; an agreement which becomes still closer if we take into consideration the probable effect of gravitation in increasing the density of the central portions in a mass of the size of the earth.

A consideration therefore of all the facts known with regard to the specific gravity of terrestrial and extra-terrestrial rocks, as well as of the earth itself, points to the conclusion that the interior portions of the planet are largely composed of metallic substances.

Texture.—The texture of a rock depends on the shape, size, physical condition and mode of arrangement of the individual constituents. The term structure is sometimes used in the same sense, but it is more frequently employed with reference to the behaviour of rocks in large masses.

When an igneous rock contains a number of more or less spherical or elliptical cavities, due to the escape of gases and vapours during the process of cooling, it is said to be *vesicular*. When the cavities are very numerous, as in pumice, it is said to be *pumiceous* or *scoriaceous*. When the cavities have been filled up with secondary minerals the rock becomes *amygdaloidal*. In certain cases cavities, occupied by secondary minerals, have been produced by the partial decomposition of an originally homogeneous rock. Such cavities are termed pseudo-amygdaloids. They may be distinguished from true amygdaloids, at any rate in most cases, by their irregularity in form.

Rocks which were solid throughout when first formed present a number of important modifications of texture. Such a rock may be composed entirely of crystals or crystalline grains, in which case it is said to be *holocrystalline;* or it may be composed partly of crystalline and partly of amorphous matter, in which case it is said to be *semi-crystalline;* or, again, it may consist almost entirely of glass, in which case it is said to be *glassy* or *vitreous*. In the holocrystalline rocks two important varieties of texture, depending on the relative sizes of the constituents, are recognised. When the constituents are of tolerably uniform size, and intimately intercrystallised, the rock is said to be *granular*. When, on the other hand, certain constituents occur as large and more or less perfect crystals in a matrix of finer grain, the rock is said to be *porphyritic*. The rocks which are composed partly of crystalline and partly of amorphous matter are usually regarded as porphyritic. The essential feature of the porphyritic texture, as thus defined, is the occurrence of certain crystalline constituents which are differentiated from those forming the mass of the rock, the groundmass or matrix, by reason of their size.

When the porphyritic texture can be recognised with the naked eye the rock is said to be *macro-porphyritic:* when it can only be made out distinctly by the use of the microscope it is described as *micro-porphyritic*.

Professor Rosenbusch has proposed that the above use of the term porphyritic should be dropped, and its meaning so extended as to include certain rocks in which the crystalline constituents are of tolerably uniform dimensions, but

belong to different phases of consolidation. It does not seem probable to the present writer that the views of Professor ROSENBUSCH, so far as they affect nomenclature, are likely to meet with general acceptance; but as the arguments advanced by him are of great importance, and incidentally involve a discussion of the conditions under which different kinds of igneous rock consolidate, it seems desirable that they should be considered at some length.

In the paper dealing with this subject[1] the common constituents of igneous rocks are divided into four groups—

(1) The ores and accessory constituents. (Magnetite, hematite, ilmenite, apatite, zircon, spinelle, sphene, &c.)
(2) The ferro-magnesian constituents. (Biotite, hornblende, pyroxene, olivine.)
(3) The felspathic constituents. (Felspar, nepheline, leucite, melilite, sodalite, hauyn.)
(4) Free silica.

The members of the first are, according to the author, always the first to form in the process of crystallisation and, as a natural consequence, they show the most perfect crystalline form. Those of the second and third groups differ as to their relative order of crystallisation in different cases. In the granites and syenites the ferro-magnesian minerals precede the felspathic constituents; in the diabases (dolerites and gabbros) the relation is frequently reversed. We have thus two types of granular structure—*granitisch-körnig* and *diabasich-körnig*. Where two or more members of the second and third groups are present in the same rock, the order of crystallisation is usually that of increasing acidity. Thus, olivine is formed before biotite, pyroxene and amphibole; biotite before either of the last-mentioned minerals. Again, triclinic are usually formed before monoclinic felspars. In the granular rocks of the granitic group (granitisch-körnig), the order of crystallisation and, consequently, the perfection of crystallographic form correspond to decreasing basicity; the ores and accessory constituents are the first formed minerals, quartz is the youngest product in the process of rock-building. The author considers that, in the entire group of the holocrystalline granular rocks, after the crystallisation of the ores and accessory constituents, the silicates separate in the order of decreasing basicity and free silica, when present, is the last substance to crystallise. Moreover, in the formation of these rocks the process of crystallisation is continuous. The minerals of each of the above groups belong to one and the same period; in other words there is no *recurrence of phase* during the process of consolidation.

In typical porphyritic rocks the porphyritic crystals are sharply differentiated from the ground-mass which may be holocrystalline, mixed

(1) Über das Wesen der körnigen und porphyrischen structur bei Massengesteinen. N.J. 1882, Band VI., p. 1.

or amorphous (microfelsitic or glassy). The differentiation is due to the fact that after the formation of the porphyritic minerals the conditions of consolidation were changed by the eruption or intrusion of the mass or by some other cause. If the porphyritic minerals be compared with each other it will be seen that they have crystallised in the order of increasing acidity; and so also with regard to the minerals of the groundmass. But if the rock be considered as whole the fact which strikes one is that there has been a recurrence of phase. Minerals of the second and third groups and even quartz, as in the case of the quartz-porphyries, may have been produced at two distinct periods in the process of crystallisation. Prof. Rosenbusch concludes by proposing that henceforth the term *granular* should be applied to rocks in which the process of crystallisation has been continuous, and the term *porphyritic* to rocks in which there has been recurrence of phase in the sense explained above.

In the discussion of this important paper the first point that demands attention is the statement with reference to the order of crystallisation That the law of decreasing basicity is true in a broad and general way, in the case of many rocks, will in all probability be admitted by all petrographers; at the same time it cannot be doubted that exceptions are very numerous. Some of these exceptions may, as Professor Rosenbusch points out, be apparent rather than real; and due to the fact that, in the present unsatisfactory state of our knowledge with regard to the molecular constitution of the complex silicates, we are not in a position to define with precision the meaning of the term *basicity*. If we compare the unisilicate olivine (ratio of oxygen combined with Mg. and Fe. to that combined with Si. = 1 : 1) with the bisilicates—augite, enstatite, &c. (ratio of oxygen combined with Mg., Fe. and Ca. to that combined with Si. = 1 : 2)—the law is strikingly illustrated; for olivine appears always to be the first formed mineral when it occurs in the presence of the bisilicates in ordinary igneous rocks. In the case of the felspars the law is also true as a general rule. Thus Fouqué [1] has shown that the porphyritic felspars in the Santorin lavas are labradorite (oxygen ratio = 1 : 3 : 6), or in some cases anorthite (oxygen ratio = 1 : 3 : 4), whereas the felspars of the groundmass have approximately the composition of albite (oxygen ratio = 1 : 3 : 12).

Optical and chemical researches by subsequent observers have tended to establish the general truth of the law here referred to, at any rate in the large and important group of rocks to which the terms andesite and porphyrite are applied. The earlier porphyritic felspars are usually anorthite, bytownite or labradorite; the later microlitic felspars are oligoclase or albite. Moreover when these rocks possess any residual glass this substance, as has been already shown, differs in composition from the entire rock exactly as it would on the assumption that the law of Rosenbusch is correct. Where monoclinic and triclinic felspars are both present, the latter are usually seen to have been first produced.

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(1) Santorin et ses Eruptions. Paris, 1879.

When the members of the second group are compared with those of the third, the law of ROSENBUSCH becomes more difficult of application. The following facts may be mentioned as exceptions to the law. Magnetite is not always the first product of consolidation. It may be formed at almost any stage in the process of consolidation.[1] Quartz is anterior in date to the felspar in the case of many granites.[2] Oligoclase is sometimes found as a zone surrounding orthoclase.[3]

There can be no doubt that the conditions which govern the formation of crystals in an igneous magma are extremely complex. The chemical composition of the magma and the physical conditions (*e.g.* temperature and pressure) under which consolidation is effected are probably the most important factors. One of the problems of the future will be to determine how these factors stand related to the resulting mineral compounds.

We have now to consider the second point raised in the paper by Professor ROSENBUSCH; namely the recurrence of phase in typical porphyritic rocks. In these rocks members of the second, third and fourth groups occur as porphyritic elements and as constituents of the groundmass. In certain quartz-porphyries we find quartz and felspar (orthoclase) occurring as porphyritic elements and also as constituents of the groundmass. In andesites, porphyrites and certain dolerites (*e.g.* those of Etna), felspar (triclinic) and ferro-magnesian minerals occur under the same circumstances. It is obvious that in these rocks the members of the second and third groups have not been all produced at one and the same period, or under the same conditions. This fact, of course, has long been recognised, and its importance has been especially insisted upon by Messrs. FOUQUÉ & LÉVY who separate the original minerals into two groups:—(1) those formed prior to the final act of consolidation, (2) those formed in connection with final consolidation.

The third point in Professor ROSENBUSCH's paper is the proposal to make the recurrence of phase the essential feature indicated by the term porphyritic. M. LÉVY [4] has clearly shown that in many typical granites, which do not contain any definite porphyritic crystals, it is possible to recognise, by the use of the microscope, that the constituents belong to two distinct periods. The minerals of the earlier period are not distinguished by reason of their size; but by the fact that they show more perfect form, or else occur in fragments. Again, in the basic rocks of granular aspect we find the same fact illustrated. The Whin Sill, the Hett dyke and the High Green dyke, for example, all of which occur in the north of England, are composed of rocks which are thoroughly granular to all appearance, and yet if a large series of slides be examined it will be seen that they contain here and there crystals of felspar, which must have been formed before the consolidation of the main mass of the rock, and which would therefore make the rock porphyritic if the definition of Professor ROSENBUSCH were adopted. It is

(1) FOUQUÉ & LÉVY. Synthése des Minéraux et des Roches. p. 51.

(2) J. ROTH. Allgemeine und Chemische Geologie. Band II, p. 50.

(3) DE LA VALÉE POUSSIN ET RÉNARD. Memoire sur les Roches dites Plutoniennes, &c., p. 175.

(4) De quelques charactères microscopiques des roches anciennes. B.S.G.F., Se. III., Vol. III., p. 199.

urged therefore against the adoption of this definition:—(1) that it would be impossible to recognise a granular rock without the examination of a large series of microscopic preparations, and (2) it would so alter the recognised limits of granular and porphyritic rocks as to introduce a large amount of confusion—the latter group would be enormously increased at the expense of the former.

In what follows a rock will be said to be granular when it is entirely or almost entirely composed of crystalline constituents of uniform size, and porphyritic when any of the crystalline constituents stand out in a marked manner in consequence of size, and the extent to which crystalline form is developed.

Consider now the relation between the granular and porphyritic rocks. The first fact that strikes one is that the granular texture is especially characteristic of plutonic; the porphyritic texture of volcanic masses. Rhyolitic, andesitic and certain doleritic lavas exhibit the porphyritic textures in the greatest perfection. Intrusive masses of granite, diorite, dolerite (diabase) and gabbro, on the other hand, usually furnish good illustrations of the granular texture. How is this fact to be accounted for? The explanation which naturally suggests itself is this. Lavas when they reach the surface frequently contain crystals which have been developed before eruption, and these crystals give the porphyritic texture after final consolidation. The matter which is in the liquid state at the time of eruption consolidates as the groundmass of the rock. If this view be accepted, and it certainly is applicable to a large number of cases, we see that the porphyritic texture is the expression of the fact that the conditions of consolidation changed abruptly at the period of eruption. After crystalline growth had progressed to a certain extent the semi-molten mass moved upward, and final consolidation took place under different conditions.

The porphyritic texture, however, is not only found in lavas but also in veins, dykes and intrusive masses. The material of veins and dykes merely represents lava which has failed to reach the surface, and therefore the explanation given above will apply to these cases with only a slight modification.

The relations between the granular and porphyritic textures in intrusive masses is of great interest. In many cases a perfectly gradual transition from one texture to the other may be observed; the central portions of a mass frequently showing a granular texture, while the marginal portions and the apophyses are more or less porphyritic. Thus a dyke in the Hartz, known as the Bode-Gang [1] which is connected with the granite-mass of the Rammberg is a true quartz-porphyry, containing in places an amorphous base and quartz-crystals with a few liquid- and many glass-inclusions. A somewhat similar dyke occurs at Mt. Willard in New Hampshire.[2] It is an off-shoot from the main mass of Albany granite. The central portions are holocrystalline and the texture is thoroughly granular. The quartz occurs

(1) Lossen.—Der Bode-Gang im Hartz. Z.D.G.G., 1874, XXVI., 856.

(2) Hawes.—The Albany Granite and its contact phenomena. A.J.S. XXI. p. 21, Jan. 1881.

as irregular grains without any approach to crystalline form. At a distance of fifteen feet from the junction the rock consists of crystals of orthoclase and bipyramidal quartz embedded in a matrix which cannot be resolved into distinct constituents by the naked eye. At the actual junction the matrix becomes hornstone-like in appearance. Many similar illustrations of the relation of granite to quartz-porphyry might be quoted.

In the intermediate and basic groups we find similar relations between the granular and porphyritic textures in large masses. The rocks of the Washoe district in North America may be quoted as an illustration of this statement so far as the intermediate group is concerned. This case is of considerable importance because the rocks have been well exposed in consequence of the extensive mining operations connected with the Comstock Lode. Moreover the facts have been described by a number of competent observers.[1] The rocks involved are pyroxene-andesite, hornblende-andesite, diabase and diorite. The pyroxene- and hornblende-andesites are typical porphyritic rocks, containing more or less amorphous matter in the groundmass. The diabase and diorite are holocrystalline rocks, usually porphyritic, but sometimes perfectly granular. The earlier observers, RICHTHOFEN, ZIRKEL and BECKER, acting under the impression that the granular texture and other characters possessed by the diabase and diorite were especially characteristic of pre-tertiary rocks, separated these rocks from the pyroxene- and hornblende-andesites which they considered to be of Tertiary age. Messrs. HAGUE and IDDINGS have recently shown that the diabase and pyroxene-andesite are merely textural modifications of the same rock-mass; and that the same is true of the diorite and hornblende-andesite. Diabase shades into pyroxene-andesite; diorite into hornblende-andesite. The granular texture is developed in the greatest perfection about Mt. Davidson. In proceeding outwards from this mountain it gradually gives place to the porphyritic texture.

All these facts point to the conclusion that the texture of a rock is determined by the conditions of consolidation; and the most reasonable supposition is that the coarse granular texture is characteristic of slow consolidation under considerable pressure and uniformly changing conditions, while the porphyritic texture is produced by one or more abrupt changes in the environment of the consolidating magma.

In igneous rocks which retain their original characters it is possible to determine, in most cases, the order of crystallisation, by observing the extent to which crystalline form is developed and the various ways in which the different minerals interfere with and enclose each other. In some of the typical granular rocks, however, this becomes impossible. The principal mineral constituents mutually interfere with each other as if they had crystallised simultaneously. Now it is interesting to note that this latter feature is the

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(1) RICHTHOFEN. The Comstock Lode, San Francisco, 1868.

ZIRKEL. Microscopical Petrography, U.S. Geol. Expl., 40th Parallel, 1870.

BECKER, G. F., Geology of the Comstock Lode.

HAGUE AND IDDINGS. On the development of crystallisation in the igneous rocks of the Washoe District. Bulletin of the U.S. Geol. Survey, No. 17, 1885.

special characteristic of the crystalline schists. In these rocks the principal mineral constituents appear to have crystallised simultaneously, not successively. In a typical hornblende-schist, for example, composed of hornblende, felspar and quartz, none of these minerals possess definite external form. There is no indication of one of these minerals having been formed before another. The author has shown that a hornblende-schist of the above type may be produced by the metamorphism of a dolerite (diabase). The minerals of the schist appear to be almost entirely of secondary origin and to be due to the molecular re-arrangement of the original constituents under enormous pressure, without any great elevation of temperature, or at any rate without anything like a refusion of the original rock. If this be admitted, then it follows that a holo-crystalline rock having a certain definite chemical composition, may be produced either by the *successive* formation of crystals during the cooling down of an igneous magma or by the *simultaneous* formation of crystals in a solid mass at a lower temperature but under enormous pressure. The minerals formed in the two cases will in general not be the same.

We have now to consider other textural peculiarities of igneous rocks. Holocrystalline non-porphyritic rocks present several varieties of texture depending on the mutual arrangement of the constituent minerals. The term *granitic* is used to express that texture which is the special characteristic of granites. When the grain of the rock is so fine that the texture can only be made out by the use of the microscope it is said to be *micro-granitic.*

The term *pegmatitic* is used to express the texture which is well illustrated by graphic granite. In this case the rock, or portion of the rock, to which the term is applied is composed of two minerals which occur in more or less isolated patches, but in such a way that different patches of one and the same mineral possess the same optic orientation over a considerable area, and behave therefore as if they belonged to one and the same crystalline individual. Thus, when a patch of considerable size is examined under crossed nicols, it is observed that in one position of the stage all the separate portions of one mineral are extinguished, and in another position all the separate portions of the other mineral. Quartz and felspar are the substances which show the texture most frequently. When it can only be made out by the use of the microscope it is said to be *micro-pegmatitic.* It sometimes happens that the two minerals have a kind of radial arrangement, one of them forming, as it were, a kind of nucleus. To express this texture the term "centric" is used.

Although the "centric" and "pegmatitic" textures are especially characteristic of quartz and felspar they are exhibited also by other minerals, as, for instance, garnet and felspar, omphacite and felspar, augite and felspar, orthoclase and plagioclase.[1] Professor ROSENBUSCH uses the term *granophyric* to express these textures when they are due to quartz and felspar.

Another very important variety of texture is that which M. LÉVY

(1) F. BECKE. T.M.M. Neue Folge, Band IV., Plate III., Figs. 11, 12, 15, 17.

designates by the term *ophitic*. It is well seen in the "ophites" of the Pyrennees. In this country we find it admirably developed in the dolerites (diabases) of all ages from the Cambrian, or possibly even pre-Cambrian, down to the Tertiary period. Thus, it is well exhibited in the diabases (altered dolerites) associated with the Cambrian and Silurian rocks of Wales, in similar rocks associated with Carboniferous strata of Derbyshire and in the Tertiary dolerites of the west of Scotland. It is equally characteristic of the dolerites of the Färoe Islands and of Iceland. (2)

In all these cases the texture is due to the mutual relations of the two minerals, felspar and pyroxene. The pyroxene, as observed in thin sections, occurs in large irregular plates, and the felspars in lath-shaped forms (see Plate X., Fig. I.) The felspars penetrate the plates of pyroxene in all directions and are frequently enclosed within the pyroxene-substance. Each large plate (ophitic plate as it may be called) of pyroxene possesses uniform optic orientation and therefore extinguishes in one position under crossed nicols. The crystals of felspar on the other hand possess independent optical characters. It is obvious that this texture implies that the felspar has crystallised before the pyroxene. The former mineral shows more or less definite crystalline form—it is automorphic—the latter mineral plays, as it were, the rôle of ground-mass, and in crystallising has taken its form entirely from the disposition of adjacent crystals—it is xenomorphic. The texture is especially characteristic of the diabases of Continental petrographers and is designated diabasich-körnig by Professor Rosenbusch.

Although the term *ophitic*, which will be employed in the present work, was originally applied to this texture so far as it is dependent on the minerals felspar and pyroxene, there seems no reason why it should not be extended to similar associations of other minerals. The essential feature of the texture is the occurrence of large irregular crystalline masses of one mineral interrupted by detached crystals or grains of a second mineral. It differs from the pegmatitic texture in that the different portions of the second mineral possess independent optical characters—they do not stand related to each other as different portions of one and the same crystal. (1) If this extension be admitted then the following pairs of minerals also give rise to the ophitic texture: olivine and bronzite, olivine and hornblende, olivine and augite, olivine and felspar.

The term *granulitic*, as applied to texture has been used differently by different authors. In certain granitic rocks, especially those which contain white mica as one of the constituents, the ground-mass, as it were, of the rock is frequently composed of a number of crystalline grains of uniform size. The appearance under the microscope of this ground-mass reminds one of that of many quartzites. Under polarised light it appears as a brilliantly coloured mosaic if the slide be moderately thick. An igneous rock wholly or partially composed of crystalline grains of this character is said by M. Lévy to possess a granulitic texture. Professor Judd uses the

(1) Bréon. Géologie d' Iceland, Paris, 1885.

(2) There also appears to be a genetic difference between the two textures; thus the pegmatitic texture appears to be due to simultaneous, the ophitic to successive crystallisation.

term *granulitic* in a different sense in his paper on the "Gabbros, dolerites and basalt of the West of Scotland." It is applied by him to a rock in which only one of the constituents, viz. augite, occurs in the form of granules. In the granulitic dolerites and basalts the felspar gives lath-shaped sections. When the term *granulitic* is used in the present work the name of the author followed will be appended in brackets.

The porphyritic rocks taken as a whole may be separated into more or less distinct groups according to the modifications of the ground-mass. Thus:—

(1) Ground-mass granitic, *e.g.*, porphyritic granites.
(2) Ground-mass micro-granitic, *e.g.*, micro-granites.
(3) Ground-mass pegmatitic or micro-pegmatitic, *e.g.*, certain granites and quartz-felsites, granophyres (ROSENBUSCH.)
(4) Ground-mass petrosiliceous, *e.g.*, certain quartz-felsites.
(5) Ground-mass microlitic, with or without glass; *e.g.*, many andesites and porphyrites.
(6) Ground-mass crystallitic, glass always present in the unaltered rock; *e.g.*, certain basalts with globulitic base.
(7) Ground-mass vitreous, *e.g.*, porphyritic pitchstones and obsidians. Rocks of this group may be still further subdivided according to the presence or absence of perlitic and spherulitic structures.

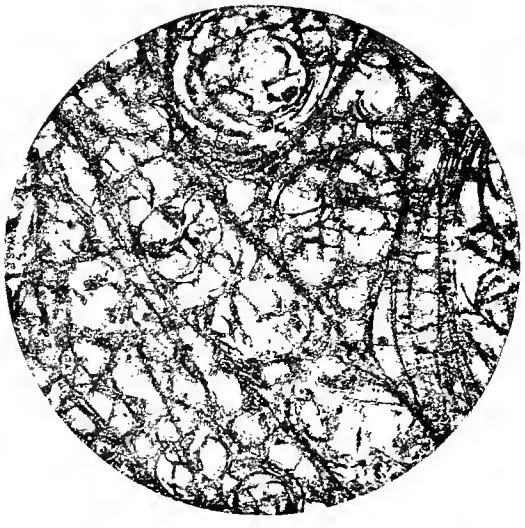
It is not intended to imply that these different groups are sharply divided from each other. Transitional forms often occur, and it frequently happens that two or more of the above types of groundmass are found in one and the same rock-mass. Here as elsewhere in petrography, and, indeed, in every branch of natural science, we find that the facts of nature refuse to accommodate themselves to any cut and dried system of classification. Such a system can only be established by ignoring some of the most important facts. Any attempt, therefore, to introduce the rigidity of the definitions of geometry into the terms used to express natural phenomena must of necessity result in the formation of a terminology which is inadequate for the purpose for which it is employed.

The petrosiliceous texture referred to above calls for more detailed description. It is especially characteristic of a large and important group of rocks, containing a high percentage of silica and belonging as a rule to the older geological periods. These rocks have been variously described under the names quartz-porphyry, quartz-felsite, felsite-porphyry, ortho-felsite, elvanite, &c. Petrosiliceous or felsitic matter—the latter term though not entirely free from objection, will be more frequently employed in the present work—is compact and stony in appearance, and agrees in chemical composition with a mixture of quartz and orthoclase. It is mentioned in the above classification as though it were distinct from the groundmass of the micro-granites and granophyres, but the only difference that can be relied upon at present is a negative one. In the latter case the substance is clearly recognised under the microscope to be holo-crystalline and to consist of the two minerals, quartz and felspar, whereas in the former case this is impossible. Under crossed

nicols felsitic matter gives a distinct reaction, the field possessing a peculiar speckled appearance, but the boundaries of the double-refracting particles cannot be recognised. These appearances can be explained, in many cases by the assumption that we are dealing with an aggregate of mineral particles so small as to overlap each other in the thinnest possible sections. It would, however, probably be a mistake to suppose that in every case this felsitic matter is holo-crystalline. If a small quantity of amorphous matter were present it might be impossible to recognise it. All that we can say with certainty at present is that the individual constituents of this perplexing substance are of ultra-microscopic dimensions.

If the term *felsitic* be used in a macroscopic sense it will include the groundmass of the micro-granites, granophyres and felsites proper.

The microlitic, crystallitic and spherulitic textures do not call for any detailed description in this connection. In a true glass the only texture which requires notice is the *perlitic*. This is due to a number of more or less



circular or spiral cracks which are produced in consequence of contraction at the time of consolidation. The case figured is that of a pitchstone from Meissen, in which a certain amount of alteration has taken place along the cracks, thus making them more conspicuous than is usually the case. Rocks possessing this texture are often termed perlites; but, as they possess the other characters of pitchstones and obsidians, and the texture is one which can be produced in other substances, such for instance as Canada balsam, it seems better to adopt the suggestion of Mr. Rutley, and use only the adjective perlitic. The rocks in question would then be termed perlitic pitchstones and obsidians.

In dealing with the textural characteristics of igneous rocks we have not only to take into consideration the mutual relations of the individual constituents, but also their relations to the rock-mass as a whole. In the normal plutonic rocks the texture as a rule is uniform, there are no directions

or planes marked out by textural peculiarities. This, however, is not always the case. It sometimes happens that a marked parallel arrangement may be observed. Thus, in certain eruptive granites the flat faces of the mica plates, or of the larger felspar crystals, are arranged parallel to each other and to certain larger structural features in the rock-mass. Such an arrangement, if original, must be attributed to differential motion in the mass after certain constituents have been formed, but before final consolidation. It is an instance of fluidal structure. In the volcanic rocks this fluidal structure is much more common. Inasmuch as the differential motion is caused by the friction of the semi-molten matter with the boundary walls in the case of an intrusive mass, and with the surface over which it flows in the case of a lava current, it follows that the textural planes above referred to will stand in direct relation to the external surfaces of the rock-mass.

A parallel arrangement of the crystalline constituents is the special characteristic of the crystalline schists, and the term foliation is applied to this arrangement, as seen in these rocks. It has recently been shown [1] that many crystalline schists have been produced by the mechanical metamorphism of igneous rocks, and that the foliated texture is therefore of secondary origin. The discussion of this question is deferred for the present, but the above remarks are introduced for the purpose of indicating the necessity of caution in determining whether the parallel arrangement in any given case is original or secondary.

(1) J. Lehmann. Die Entstehung der alt-krystallinischen Schiefer-gesteine. Bonn, 1884.

CHAPTER IV.

Classification of Igneous Rocks.

EVERY student of geology experiences the greatest difficulty in giving names to rocks, and this difficulty is shared to a great extent by those who have had a considerable amount of experience. It is tolerably easy now-a-days to describe a rock, to ascertain and record its chemical and mineralogical composition and textural characteristics; but it is by no means so easy to recognise its position in a natural system of classification.

The difficulty arises partly in consequence of the nature of the subject and partly in consequence of the absence of agreement amongst petrographers as to the first principles upon which petrographical classification should be based. The object of the present chapter is not to propose any new system, but to consider the question of classification from a general point of view and to call attention to certain points which strike the author as being of considerable importance.

In the first place we may ask ourselves the question: Is there any one natural system of rock-classification? This is by no means easy to answer, but we may at least call attention to certain radical differences between rocks and the objects with which the workers in the other branches of the natural history sciences have to deal. A consideration of these differences will show that the biologist and the mineralogist have certain advantages over the petrographer so far as matters relating to classification are concerned.

Modern biology recognises the fact that the natural system of classification, so far as living objects are concerned, is the one which best expresses the mutual relations of organisms from the point of view of evolution. In doubtful cases the biologist applies, where possible, the test of embryological development, and this test is accepted on all hands as conclusive. It may be urged that the recognition of the principle of "descent with modification" is of comparatively modern date, and that its introduction has not seriously disturbed the old established system. This is of course true, but then it must be remembered that the unanimity which existed amongst biologists before the days of Darwin, on matters relating to classification, was the manifestation of the great truth which he was mainly instrumental in establishing.

It thus appears that a principle of the utmost generality underlies and furnishes, as it were, the justification of biological classification. Now in petrography there is no generally recognised principle in any way comparable

to the one referred to, and the absence of unanimity amongst the workers in this science may possibly indicate that no such principle exists. (1)

Again, looking at rocks and organisms without any regard to ætiological considerations, there can be no doubt that the individuals and groups of individuals are much better defined among the latter than among the former. Indeed, if we take our idea of the precision which should attach to the term *species* from the organic world then this term is unquestionably out of place as applied to groups of rocks. (2)

Consider now the case of the mineralogist. A mineral is *a definite chemical compound.* Its composition is either constant, or the differences can be explained by introducing the principle of isomorphism. The fundamental law of chemistry—the law of definite combining proportions—comes in, therefore, and gives precision to mineralogical classification. It furnishes a criterion by which the independent existence of a mineral species may be tested. Now rocks are as a general rule aggregates of minerals, and the relative proportions of the different constituents are not subject to any definite laws. By the appearance or disappearance of certain minerals one variety of rock shades into another by the most imperceptible gradations. It is often as difficult to fix the point at which one variety of rock ends and another begins as it is to fix the point at which one colour ends and another begins, in the continuous spectrum of white light.

It is impossible to give a distinct name to every tint in the spectrum, and it is equally impossible to give a distinct name to every kind of mineral aggregate. We can, however, indicate any particular tint by reference to the principal colours; and so, with rocks, we can often indicate the characters of a particular specimen by referring to well marked types when it is impossible or unadvisable to use a distinctive name.

These considerations show therefore that the biologist and mineralogist have immense advantages over the petrographer in all matters relating to classification. If we endeavour to define these advantages more precisely we see that they depend, mainly, on the fact that organisims and minerals possess an individuality which is much more definite than that of rock specimens. The form and structure of an organism are mainly determined by the properties which it has inherited from its ancestors, and only to a very subordinate extent by its environment. In the same way the form and structure of a mineral are determined mainly by the inherent properties of the chemical compound. Rock specimens, on the other hand, are merely fragments which may or may not be average samples of the larger masses from which they have been broken. They possess individuality only in a very subordinate sense. Their external form is merely an accident depending on the manner in which the fragment has been detached; their texture is mainly determined by the conditions under which consolidation has been effected, and only to a limited extent by the composition of the magma.

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(1) BUNSEN'S law is the only one that may possibly render a qualification of this sentence necessary.

(2) J. ROTH.—Allgemeine und chemische Geologie. Band II., p. 41.

The petrographer who is examining a hand specimen is very much in the position of a biologist who is dealing with a small fragment of some unknown organism. Under such circumstances he (the biologist) does not endeavour to give the fragment a distinct name, but to discover the nature of the organism of which it formed a part, and the relation of the fragment to the whole. Such individuality as rocks possess is dependent on their relation to other rocks; or, in other words, on their mode of occurrence in the field. The rock specimen with which the petrographer deals in his laboratory is, therefore, only a fragment; and his object should be not merely to describe the characters of the fragment, but also to determine its relation to the larger mass of which it formed a part.

Remembering then, that rocks are aggregates; that different varieties often shade into each other by the most insensible gradations; and that rock specimens possess in themselves no marked individuality, we conclude that the primary object of the petrographer should be to *describe* rather than to *name* the specimens which come under his notice; and, further, that in framing a terminology he should endeavour to make it as elastic as possible, in consequence of the extremely protean nature of the objects with which he deals. It cannot be too often remembered that language is merely a means to an end, and that to import into the nomenclature of a science a greater amount of rigidity than is warranted by the facts of nature, tends to retard rather than to assist the growth of knowledge.

Much of the difficulty which the petrographer experiences will be removed if he distinctly recognises that it is no part of his duty to give a definite name to every variety of rock which comes under his notice.

As we must have a classification of some kind, for convenience of description, it now remains for us to consider the principles available for such a classification, so far as the igneous rocks are concerned. The characters of igneous rocks group themselves under the following heads:—

(1) Chemical composition.
(2) Mineralogical composition.
(3) Texture.
(4) Mode of occurrence in the field; *e.g.*, relations to surrounding rocks, structural features, &c.
(5) Origin.
(6) Geological age (distribution in time).
(7) Locality (distribution in space).

It is agreed on all hands that great importance should be attached to the first three groups of characters. The principal difference amongst petrographers has reference to the value which should be attached to geological age. The dominant school of petrography upon the Continent proposes to make geological age a primary factor in the classification of igneous rocks—to distinguish sharply between pre-tertiary and post-cretaceous rocks—and to use a different nomenclature for the rocks of the two periods, even when they are absolutely identical in composition, texture

and mode of occurrence.[1] Thus, the ophitic plagioclase-augite-olivine rock of Tideswell Dale, for example, which is associated with carboniferous strata would be termed an olivine-diabase; whereas rocks having absolutely the same composition, and micro-structure from Tobermory (Mull), Portree (Skye) and Iceland, which are of Tertiary age, would be termed dolerites. Again, the rock with a somewhat resinous lustre, containing porphyritic crystals of labradorite, hypersthene and augite, embedded in a microlitic groundmass, from Carhope on the Coquet, would be termed enstatite- or hypersthene-porphyrite, because it is of old-red-sandstone age. The same rock from St. Egidi (Steiermark), the Rocky Mountain region of North America, and the Andes would be termed enstatite- or hypersthene-andesite; the only difference being that in the last-mentioned localities the rock in question is of Tertiary age.[2] English, and, to a certain extent, also American petrographers,[3] do not accept this principle, and, as a natural consequence, great confusion arises in petrographical nomenclature.

While declining to accept geological age as a primary factor in classification, in common with all British petrographers, the present writer is strongly of opinion that, if possible, it should receive indirect expression. This position may be illustrated as follows. In deciding on the relative importance, for classificatory purposes, of the characters presented by fossils, the palæontologist lays special stress on those which stand in any way related to the organisation of the living animal. Minute peculiarities are, on this account, often of more value than others which are relatively conspicuous. So, when any peculiarity of texture or composition can be shown to characterise rocks of a particular period, that peculiarity should be utilised for purposes of classification. In precisely the same way facts with regard to origin, mode of occurrence and even geographical distribution may receive indirect expression in classification.

If this point of view be accepted then it follows that petrographical classification should be based primarily on facts which can be ascertained by the examination of hand specimens; and that facts with regard to origin, age, mode of occurrence and geographical distribution should only receive expression in classification in so far as they stand related to peculiarities of texture and composition; at the same time the greatest importance should be attached to the former class of facts in deciding on the relative value of the latter.

The Continental system of classification is of course based on the real or supposed fact that peculiarities of texture and composition stand in direct relation to geological age. The only author who appears to have treated this subject in a systematic way and from a modern petrographical stand-point is FRENZEL.[4]

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(1) ROSENBUSCH. Mikroskopische Physiographie der massigen Gesteine.

(2) It will be understood that these cases are merely quoted for the purpose of emphasising the argument. Others might be selected.

(3) WADSWORTH. Classification of Rocks. Bull. Mus. Comp. Zool. Massachusetts. 1879.
DUTTON. Geology of the High Plateaus of Utah. 1880.

(4) Über die Abhangigkeit der mineralogischen Zusammensetzung und Structur der Massengesteine vom geologischen Alter. Zeit. f.d. Ges. Naturw. Band LV. 1882. p. 1.

This author holds the non-uniformitarian view with regard to igneous phenomena. He considers that the general conditions of eruption upon the planet have appreciably changed during the period of time covered by our fossiliferous deposits; and that the differences observed between the igneous products of different periods are due, in a great measure, to this change. In considering the general question of the connection between age and the other characters of igneous rocks it will be convenient to bear in mind the views of this author.

In dealing with the subject it is important to distinguish between original and secondary characters. Rocks of different ages, which are identical so far as original characters are concerned, may differ considerably in consequence of alteration. A difference of this kind, though it may be of use in classification, does not of course indicate any variation in the character of igneous phenomena. The important question we have first to ask ourselves then is this: Are there any marked differences between the igneous rocks of different periods so far as original characters are concerned? The answer to this question will depend very largely on our method of treating the subject and on the extent of our field of view.

Igneous rocks may consolidate at the surface in the form of lavas and fragmental rocks; near the surface in veins and dykes; and at considerable depths beneath the surface in large masses. Rocks which form at the surface have a certain set of characters; those which form beneath the surface have another set of characters. The rocks of the former group are often scoriaceous, vesicular, amygdaloidal and porphyritic. They frequently contain more or less amorphous matter and are associated with fragmental rocks of similar composition. The rocks of the latter group are usually solid throughout, coarse in grain, granular in texture and holo-crystalline. They are never associated with contemporaneous fragmental rocks. Now in comparing the igneous rocks of different periods with each other for the purpose of determining whether any change has occurred in the character of igneous phenomena during geological time, it is obviously necessary that the comparison should be instituted between rocks of the same group. The importance of this will appear at once when we reflect that the plutonic rocks associated with the older must necessarily be more numerous than those associated with the younger formations, even if igneous action has been uniform throughout geological time. This must be so for two reasons:—(1) the plutonic (deep-seated) rocks can never be directly associated with contemporaneous stratified deposits; and (2) they can only be exposed by the denudation of the overlying rock, and therefore not until a long time has elapsed since their formation.

Let us now compare the volcanic rocks of different periods with each other, and endeavour to ascertain what differences occur between them. Our views on the subject of the connection between the composition and texture of igneous rocks and geological age will vary with the extent of our field of view. If we limit our attention to a small area of the earth's surface and to a small portion of geological time, then it becomes possible to establish a connection between the geological age and the petrographical

characters of the surface products of volcanic action. This connection, however, becomes less and less marked as we extend our field of view.

It was a general opinion amongst the earlier observers that in any one volcanic district the rocks of the acid group preceded those of the basic group, and this is true to a certain extent. SCROPE,[1] however, has shown that it is not universally true. Alternations of trachytic and basaltic lavas are not uncommon. Later researches have somewhat modified the early views as to the nature of volcanic products by bringing into prominence the rocks of intermediate composition—the andesites and porphyrites.

The sequence of volcanic rocks in three important districts—the Lipari Islands,[2] the Schemnitz District of Hungary,[3] and the High Plateaux of Utah,[4]—in which the three classes of igneous rocks are represented is now known in some detail. In each of these cases immense eruptions of andesite were succeeded by eruptions of rhyolite and basalt.

It would be out of place to consider the subject here referred to at any length in a work devoted mainly to descriptive petrography. The cases mentioned will be sufficient to show that in any one cycle of volcanic activity there is a connection between age and petrographical characters.

If now we extend our field of view, so as to take into consideration the products of two or more cycles, then the connection above referred to becomes much less marked; at the same time, if we have regard only to a comparatively limited area, it is frequently possible to establish differences between the rocks of different periods. Compare, for example, the basic igneous rocks of pre-Tertiary with those of Tertiary age in Germany, Austria and Hungary. A marked difference is at once apparent. The felspathic constituent of the former is always felspar proper, whereas that of the latter is frequently leucite or nepheline. Again, if we limit the comparison to the felspar-bearing rocks a marked difference in texture may be observed. The former frequently possess the ophitic texture, whereas this is almost, if not entirely, absent from the latter. This difference depending on texture, however, absolutely breaks down if we extend our field of view so as to include the North of Ireland, west of Scotland, the Faroe Isles and Iceland. The ophitic texture is one of the most constant features in the Tertiary basalts and dolerites of those districts.

Are there, then, any differences in composition or texture, in the volcanic products of different geological periods, which are constant throughout the world? It is impossible to give a perfectly definite answer to this question in the present imperfect state of our knowledge; but we may at least call attention to the fact that rocks containing leucite, hauyn and melilite are in all cases yet known of post-cretaceous age; and that nepheline is much more abundant in post-cretaceous than in pre-tertiary rocks. It must be remembered, however, that these minerals are somewhat restricted in

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(1) The geology of the Extinct Volcanoes of Central France. 1858, p. 129. Volcanoes, 2nd Edition. 1862, p. 127.

(2) JUDD. G.M. 1875, p. 10.

(3) — Q.J.G.S., Vol. XXXII. 1876, p. 292.

(4) DUTTON. High Plateaus of Utah, Mem. U.S. Geol. Survey Rocky Mts, 1880.

their geographical distribution, and that they must not therefore be regarded as fixing absolutely the age of the rock when found in any new locality.

Consider, now, the plutonic rocks. These are much more difficult to deal with because, as they always occur in the form of intrusive masses, it is in many cases impossible to determine their age with precision. All that can be said with confidence is that they are later in date than the rocks into which they have been intruded: how much later we cannot in many cases determine. They are more abundant amongst the older than amongst the younger rocks; but, as already pointed out, it is not safe to infer from this that they were more frequently produced during the earlier, than during the later geological periods. In any case, they are not surface products, and therefore the differences which they present when compared with volcanic rocks (*e.g.*, granular texture, abundance of liquid and rarity of glass inclusions) cannot be taken as proving differences in the conditions under which the older and younger igneous rocks have been produced. These differences cannot be correlated, as FRENZEL supposes, with phases in the developmental history of the planet.

Two of the best authenticated cases of plutonic rocks of Tertiary age are the peridotites and gabbros of the Western Isles of Scotland,[1] and the granular diorite of Mount Davidson.[2] These present no differences, so far as composition, texture and inclusions are concerned, from the corresponding rocks of pre-tertiary age. In all probability future researches will greatly increase the number of plutonic rocks of pre-tertiary age. We have been reasoning in a circle to a very great extent with reference to this question. Plutonic rocks have been usually placed as pre-tertiary without the determination of their age by independent field evidence. It is, of course, possible to make a classification which shall be consistent with itself by adopting this method; but such a classification may not be consistent with the facts of nature.

If, now, we turn our attention to the secondary features of igneous rocks it is possible to establish a much closer relation between age and petrographical characters. The older rocks have been much more altered by weathering and by regional metamorphism. Pre-tertiary basalts and dolerites have been frequently, but not always, converted into diabases and melaphyres, by the former; and less frequently into chloritic and hornblendic schists by the latter. Rocks containing glassy matter have been devitrified, and hyaline rhyolites have thus been changed to felsites. Peridotitic, hornblendic, and augitic rocks have been serpentinised. At the same time the relation is not absolute. Here and there the older rocks have been preserved and the modern rocks affected. It is unnecessary to enter upon a fuller discussion of the secondary characters of rocks at present.

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(1) ZIRKEL, F. Geologische Skizzen von der Westkuste Schottlands. Z.D.G.G., 1871, p. 1-124.
JUDD. On the Secondary Rocks of Scotland. Q.J.G.S., vol. XXX., 1874, p. 220.
JUDD. On the Tertiary and Older Peridotites of Scotland. Q.J.G.S., vol. XLI., p. 354.

(2) HAGUE and IDDINGS. On the development of Crystallisation in the Igneous Rocks of the Washoe District. Bull, U.S. Geol. Survey, 1885.

Enough has been said to indicate the nature of the subject, and it will be more fully dealt with in describing the different rock types.

The foregoing discussion leads us to the conclusion that geological age should not receive direct expression in petrographical nomenclature. The petrographer should define his rock types without direct reference to age, and then describe the distribution of his types in time. He should follow in short the method of the palæontologist. A similar course should be adopted so far as matters relating to origin and geographical distribution are concerned. The classification of igneous rocks should therefore be based primarily on facts of *composition* and *texture*.

The chemical composition of an unaltered igneous rock, not containing any foreign substances, represents in a considerable number of cases, though not probably in all, the composition of the original magma by the consolidation of which it has been produced. In a previous chapter it has been shown that, if we except certain rocks which are abnormally rich in alkalies, the relations between different rocks, so far as chemical characters are concerned, may be expressed in a broad and general way by the law of BUNSEN. It seems natural, therefore, that special stress should be laid on chemical composition in formulating a classification, and that the law of BUNSEN should be made the basis of the classification. We accordingly find that modern authors recognise at least three important groups—the basic, the intermediate and the acid groups. Some authors add a fourth—the ultra-basic—to include the peridotites.

The mineralogical composition of a rock is, however, much more easily determined than its chemical composition, and accordingly it is found more convenient, in actual practice, to define rock-types by reference to their mineralogical rather than to their chemical constituents. This is the method which will be adopted in the present work for convenience of description. It must, however, be remembered that although there is of necessity a close connection between chemical and mineralogical composition, the latter is not in all cases governed by the former. One and the same magma cooling under different conditions may give rise to rocks differing somewhat in mineralogical composition.

Texture, as we have seen, stands in intimate relation to the physical conditions under which consolidation is effected, and may therefore be very conveniently utilised for the purpose of forming sub-divisions. Messrs. FOUQUÉ and LÉVY recognise two important types of texture—the *granitic* and the *trachytic*—corresponding to the division of igneous rocks generally adopted in this country into plutonic and volcanic. The granitic texture is characterised by the absence of amorphous matter and the crystallitic and microlitic products usually associated with it; and by the fact that the constituents mostly belong to one period of crystallisation. The trachytic texture is characterised by the frequent occurrence of amorphous matter; by a finely crystalline, compact, or vitreous texture; and by the fact that the crystalline constituents, in most cases, belong to at least two strongly marked periods of consolidation. There is, of course, no hard and fast line between the two types of texture. They shade into each other by the most imperceptible gradations.

The same authors recognise three varieties of each of the principal types. The varieties of the granitic type depend on the mutual relations of the constituent minerals. They are (1) the granitic type proper, (2) the pegmatitic type, and (3) the ophitic type.[1] The varieties of the trachytic type depend upon the character of the groundmass. They are (1) the petrosiliceous or felsitic type, (2) the microlitic type, (3) the vitreous type.

It will be observed that the terms *granitic* and *trachytic* as used by the French petrographers are not synonymous with the terms *granular* and *porphyritic*. *Granitic* includes the coarsely-granular and granito-porphyritic textures. *Trachytic* includes the finely granular, felso-porphyritic and vitro-porphyritic textures.

The following is the system of classification adopted in this work for convenience of description. It is essentially based on the systems of ROSENBUSCH and Messrs. FOUQUÉ and LÉVY; but of course no distinction is made between rocks of the same composition and texture merely because they have been produced at different periods. The classification is essentially a mineralogical one; but the rocks are arranged as far as possible according to BUNSEN'S law.

GROUP A.

ROCKS COMPOSED OF THE FERRO-MAGNESIAN MINERALS: OLIVINE, ENSTATITE, AUGITE, HORNBLENDE AND BIOTITE. FELSPAR ABSENT; OR, IF PRESENT, OCCURRING ONLY AS AN ACCESSORY CONSTITUENT.

(*a*) *With Olivine.*

I. OLIVINE ROCKS. *Dunite (Hochstetter).*[2]

II. OLIVINE-PYROXENE ROCKS.

Olivine-enstatite rocks. *Saxonite (Wadsworth).*[3]

Olivine-enstatite-augite rocks. *(Lherzolite. De la Méthérie).*[4]

Olivine-augite rocks. *Picrite (Tschermak).*[5]

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(1) The ophitic texture is common to plutonic and volcanic rocks.

(2) Z.D.G.G., 1864, p. 341.

(3) Lithological Studies. Cambridge, Mass., 1884, p. 85.

(4) Théorie de la Terre, vol. II., p. 281. Paris, 1797.

(5) Die Porphyrgesteine Österreichs. Wien, 1869, p. 241. The picrite of Tschermak is intrusive in cretaceous rocks. Gümbel (Die palæolithischen Eruptivgesteine des Fichtelgebirges. München, 1874, p. 38,) has proposed the term palæopicrite for a rock of similar composition, which is associated with palæozoic sediments in the Fichtelgebirge.

III. Olivine-Hornblende Rocks.

(β) *Without Olivine.*

To this division belong rocks composed of one or more of the following minerals:— Enstatite (hypersthene), hornblende, augite (diallage) and biotite.[1]

The prevailing texture amongst the rocks of Group A. is the *granitic*. Some varieties of Tschermak's picrite are *trachytic*.

Rocks of this group, or indeed of any group, are not sharply separated from each other. They shade into each other by the appearance or disappearance of certain minerals, and these transitions may sometimes be observed in one and the same rock-mass. Thus the olivine-pyroxene rocks frequently contain a certain amount of hornblende, and the olivine-hornblende rocks a certain amount of pyroxene. Again, by the coming in of felspar the rocks of the picrite group shade into those of Group B. The olivine-pyroxene rocks graduate into the olivine-dolerites, and the olivine-hornblende rocks into olivine-diorites.

APPENDIX TO GROUP A.

Serpentine.[2]

GROUP B.

ROCKS IN WHICH PLAGIOCLASE IS THE DOMINATING FELSPATHIC CONSTITUENT. NEPHELINE AND LEUCITE ABSENT. ORTHOCLASE IS FREQUENTLY PRESENT.[3]

I. Plagioclase-olivine Rocks.

(a) Granitic texture. *Forellenstein or Troctolite.*

(b) Trachytic texture. *(Not recognised).*

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(1) The terms *hornblendite* and *pyroxenite* have been proposed by Professor Dana (G.M., 1881, p. 62) for two varieties of this division; the former for rocks mainly composed of hornblende, the latter for rocks mainly composed of augite. When first described by the author these rocks were supposed to be of metamorphic origin; but they are now regarded as igneous. (A.J.S., Vol. XXVIII., p. 384). The term *pyroxenite* has been used in different senses by different writers.

(2) The *mineral* serpentine may be formed by the alteration of olivine, enstatite (bronzite) and non-aluminous hornblende and augite. The different varieties of the *rock* serpentine may therefore be designated as olivine-serpentine, enstatite- or bronzite-serpentine, hornblende-serpentine and augite-serpentine. The only typical eruptive rocks known to have yielded serpentine are those rich in olivine and enstatite.

(3) And in some cases (*e.g.*, certain quartz-diorites) it is difficult to say whether the rocks should be placed in this or the next group.

II. Plagioclase-pyroxene Rocks.

(*a*) *With Olivine.*

(1) Plagioclase-augite-olivine rocks.[2]

(*a*) Granitic texture. Felspar and augite both in the form of coarse grains. *Olivine-gabbro.*

(*b*) Texture intermediate between the granitic and trachytic. Felspars lath-shaped in section. Augite in crystals, grains, or irregular plates (ophitic). *Olivine-dolerite.*

(*c*) Trachytic texture. Finely crystalline or compact; often containing a certain amount of amorphous matter. Felspars giving lath-shaped sections. Augite of the groundmass in small crystals or granules. *Olivine-basalt.*

(2) Plagioclase-enstatite[3]-olivine rocks.

(*a*) Granitic texture. *Olivine-norite.*

(*b*) Trachytic texture. (*Not recognised*).

(β) *Without Olivine; without quartz.*

(1) Plagioclase-augite rocks.

(*a*) Granitic texture. *Gabbro.*[4]

(*b*) Texture intermediate between the granitic and the trachytic. *Dolerite.*[5]

(*c*) Trachytic texture. *Basalt;* and, in some cases, *augite-andesite.*

(2) Plagioclase-enstatite rocks.

(*a*) Granitic texture. *Norite.*

(*b*) Trachytic texture. *Enstatite-andesite.*

(3) Plagioclase-augite-enstatite rock.

(*a*) Granitic and intermediate textures. *Enstatite-gabbro and enstatite-dolerite.*

(*b*) Trachytic texture. *Enstatite-augite-andesite.*

(γ) *With quartz; without olivine.*

(*a*) Granitic and intermediate textures. *Quartz-gabbro* and *quartz-dolerite (quartz-diabase of Continental authors).*

(*b*) Trachytic texture. *Quartz-augite-andesite. Dacite (in part).*

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(2) The term augite is used as the general name for the monoclinic pyroxenes. It includes diallage and pseudo-hypersthene.

(3) It must be remembered that the term enstatite is here used to cover the entire group of rhombic pyroxenes.

(4) When the felspar is anorthite the rock is termed eucrite.

(5) Continental authors use the term diabase for all pre-tertiary rocks having this composition and texture. As we find no constant original differences between the pre-tertiary and post-cretaceous rocks of the basic group in this country it is impossible for us to adopt the Continental system of classification.

III. PLAGIOCLASE-HORNBLENDE ROCKS.

(α) *Without quartz.*

(a) Granitic texture. *Diorite.*[1]

(b) Trachytic texture. *Hornblende-andesite.*[2]

(β) *With quartz.*

(a) Granitic texture. *Quartz-diorite.*[3]

(b) Trachytic texture. *Hornblende-andesite and Quartz-hornblende-andesite, Dacite (in part).*

IV. PLAGIOCLASE-BIOTITE ROCKS.

(α) *Without quartz.*

(a) Granitic texture. *Mica-diorite.*

(b) Trachytic texture. *Mica-andesite.*

(β) *With quartz.*

(a) Granitic texture. *Quartz-mica-diorite.*

(b) Trachytic texture. *Quartz-mica-andesite, Dacite (in part).*

The plagioclase-pyroxene, plagioclase-hornblende and plagioclase-biotite rocks are not sharply separated from each other. Two or more of the ferromagnesian minerals, augite, enstatite, hornblende and biotite, usually co-exist in the same rock. These compound rocks can best be designated by terms made up in each case of the names of the constituent minerals, the textural characteristics being indicated by adjectives, or by concluding the term with such words as diorite or andesite, the former of which always implies a granitic and the latter a trachytic texture. This terminology is cumbersome, but it has the great merit of being descriptive. Moreover it is elastic, and this is an absolutely essential qualification for any terminology which deals with objects so closely connected by intermediate forms as rocks. A rigid terminology is only useful where types are rigidly defined.

APPENDIX TO GROUP B.

The changes which rocks of this group undergo when subjected to the different agents of metamorphism are very complicated and, in many cases, little understood. It is impossible, therefore, to formulate any definite system of terminology. In the present work the terms diabase, melaphyre, and porphyrite, in so far as they are used at all, will be employed merely to designate varieties of dolerite, basalt and andesite due to alteration by surface

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(1) When the felspar is anorthite we have the variety known as Corsite.

(2) The hornblende-andesites and their altered representatives, the hornblende-porphyrites, form a well characterised group of rocks. As they contain an excess of silica in the groundmass they must, however, be regarded as the porphyritic equivalents of the quartz-diorites.

(3) This includes the Tonalite of Vom Rath and the Banatite of Cotta.

agencies. In the Continental system of classification these terms are applied to the pre-tertiary representatives of the post-cretaceous dolerites, basalts and andesites.

The effects of contact and regional metamorphism on rocks of Group B have been studied only in a few cases. They will be described in the following pages, but no attempt is here made to tabulate the results already obtained.

GROUP C.

ROCKS IN WHICH ORTHOCLASE IS ABUNDANT. PLAGIOCLASE USUALLY PRESENT. NEPHELINE AND LEUCITE ABSENT.

(*a*) *Without quartz.*

I. Orthoclase-Hornblende Rocks.
- (*a*) Granitic texture. *Syenite* (*Werner*).
- (*b*) Trachytic texture. *Hornblende-trachyte*[1] *and-felsite.*

II. Orthoclase-Augite Rocks.
- (*a*) Granitic texture. *Augite-syenite.*
- (*b*) Trachytic texture. *Augite-trachyte and felsite.*

III. Orthoclase-Mica Rocks.
- (*a*) Granitic texture. *Mica-syenite or minette.*[2]
- (*b*) Trachytic. *Mica-trachyte and -felsite.*

IV. Orthoclase-Mica-Hornblende Rocks.
- (*a*) Granitic texture. *Mica-hornblende-syenite.*
- (*b*) Trachytic texture. *Mica-hornblende-trachyte and -felsite.*

(*β*) *With quartz.*
- (*a*) Granitic texture.
  - (1) Orthoclase-quartz rocks. *Aplite.*
  - (2) Orthoclase-quartz-biotite rocks. *Granitite* (*Rose*).
  - (3) Orthoclase-quartz-hornblende rocks. *Hornblende-granite.*

(1) There is, perhaps, no term in petrography which has been more widely used than trachyte. In the present work it is employed as a general term connoting a trachytic texture (*i.e.*, not granitic or granito-porphyritic), and the presence of glassy orthoclase (sanidine). Where the felspar is not glassy (orthoclase proper), the term felsite will be used in the same general sense. Sanidine is frequently associated with a glassy base, and orthoclase proper is usually associated with a micro- or crypto-crystalline groundmass.

(2) The term minette has been applied both to the granitic and trachytic varieties of this group. In the present work it will be applied only to the former.

(4) Orthoclase quartz - hornblende biotite rocks. *Hornblende-granitite.*

(5) Orthoclase-quartz-augite rocks. *Augite-granite.*

(6) Orthoclase-quartz-augite-biotite rocks. *Augite-biotite-granite or augite-granitites.*

(7) Orthoclase - quartz - muscovite rocks. *Muscovite granite.*

(8) Orthoclase-quartz-muscovite-biotite rocks. *Muscovite-biotite-granite or granite proper.*

(*b*) Trachytic texture.

(1) Non-porphyritic, compact. *Felsite.*[1]

(2) Porphyritic, with compact ground-mass. Felspar orthoclase (not sanidine).

Quartz-felsite (Field term.)[2]

(i) Ground-mass, holocrystalline; texture, micro-granitic. *Micro-granite* (*Rosenbusch*).

(ii) Ground-mass, holocrystalline; texture, micropegmatitic or pseudo-spherulitic. *Granophyre, (Rosenbusch*).

(iii) Ground-mass, cryptocrystalline or microfelsitic. *Felsophyre (Vogelsang).*

(3) Porphyritic, with compact ground-mass. Felspar sanidine. *Quartz-trachyte, Liparite or Rhyolite.*[3]

(4) Porphyritic, with glassy ground-mass. *Vitrophyre (Vogelsang); including porphyritic obsidians and pitchstones, and also the glassy (hyaline) rhyolites.*

The trachytic modifications of the acid magma often contain one or more

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(1) It must be remembered that many of the felsites are devitrified glassy rocks. See Allport, Q.J.G.S., vol. XXXIII., page 449; also Rutley, Felsitic Lavas, "Memoirs of Geological Survey of England and Wales."

(2) The term quartz-felsite as here used is not precisely equivalent to the *quartz-porphyry* of Continental authors: the latter term is more comprehensive as it includes the porphyritic pitchstones and obsidians of pre-tertiary age.

If we compare the pre-tertiary trachytic representatives of the acid magma with the corresponding rocks of later date we are struck with the greater frequency of the occurrence of glass, as a constituent of the groundmass, in the latter rocks. This is largely, if not entirely, due to devitrification having taken place in the older rocks.

(3) The term *nevadite* was introduced by Richthofen for a variety of liparite in which the porphyritic elements are so extremely numerous that the rock approaches in aspect to a granite. The typical nevadites, however, are not granitic, but trachytic in texture (see Hague and Iddings, A.J.S., vol. 27, p. 461). With regard to the use of the terms liparite and rhyolite, it seems convenient to restrict the latter term to rocks in which a flow structure is well marked.

of the ferro-magnesian minerals: biotite, hornblende, augite and enstatite. Thus we have such varieties as quartz-biotite-felsites and -trachytes; quartz-hornblende-felsites and -trachytes, &c., &c.

APPENDIX TO GROUP C.

The general remarks made with reference to Group B apply also here.

GROUP D.[1]

ROCKS CONTAINING NEPHELINE OR LEUCITE; SOMETIMES NEPHELINE AND LEUCITE.

- (*a*) *With orthoclase, anorthoclase or microcline.*
  - (*a*) Granitic texture.
    Elæolite- or nepheline-syenite.[2]
  - (*b*) Trachytic texture.
    - (1) With nepheline and sanidine. *Nepheline-phonolite or phonolite proper.*
    - (2) With leucite and sanidine. *Leucite-phonolite.*
    - (3) With leucite, nepheline and sanidine. *Leucitophyre (Rosenbusch).*
- (*β*) *With plagioclase.*
  - (1) With nepheline. *Nepheline-tephrite (Rosenbusch).*
  - (2) With leucite. *Leucite-tephrite.*
  - (3) With leucite and nepheline. *Leucite-nepheline-tephrite.*
- (*γ*) Without felspar.
  - (1) With nepheline; without olivine. *Nephelinite (Rosenbusch).*
  - (2) With leucite; without olivine. *Leucitite (Rosenbusch).*
  - (3) With nepheline and olivine. *Nepheline-basalt.*
  - (4) With leucite and olivine. *Leucite-basalt.*

(1) Rocks of this group are rich in accessory minerals—nosean, melanite, sodalite, melilite, &c., and many varieties not represented in the above scheme are accordingly recognised. It is represented in Britain, so far as we know at present, by the solitary example of the Phonolite of the Wolf Rock.

(2) Miascite, ditroite and foyaite are varieties of nepheline-syenite.

APPENDIX TO GROUP D.

Here belong the Liebenerite-porphyry (altered phonolite) and possibly also certain Teschenites.

GROUP E.

ROCKS NOT INCLUDED IN ANY OF THE PRECEDING GROUPS.

Notwithstanding the fact that the preceding classification has been made as elastic as possible, so that many mineral-aggregates, not actually mentioned, readily find a natural place within it, yet it does not include all known igneous rocks. It becomes necessary therefore to recognise another group for rocks which cannot be placed in any of the preceding. As illustrating this group we may mention the following :—

Limburgite (Rosenbusch) = augite, olivine, magnetite, and a glassy base.

Pyroxenite (Doelter),[1] *Magma-basalt (Bóricky)*[2] = augite, magnetite, and glassy base.

GROUP F.

VITREOUS ROCKS.

Rocks almost wholly composed of glass have no place in a purely mineralogical classification. They may be classified according to chemical composition and physical characters. As the glassy rocks are often only local variations of the crystalline and semi-crystalline products of volcanic action it seems most convenient to designate them by means of the terms applied to the latter, in the manner proposed by Messrs. JUDD AND COLE.[3] Thus we have liparite-glass, trachyte-glass, andesite-glass, phonolite-glass, basalt-glass, &c.

The liparite-glasses are the most abundant in nature. They are divided into two main groups according to lustre and fracture.

(1) Vitreous lustre and conchoidal fracture ; *Obsidian*
(2) Resinous lustre and splintery fracture ; *Pitchstone.*

Subordinate varieties depending on the presence or absence of perlitic, spherulitic and other structures are also recognised.

Glasses of basic composition are often termed *tachylytes*. They usually

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(1) Die Vulcane der Capverden. Graz, 1882.

(2) Petrographische Studien an den Basaltgesteinen Böhmens. Prag., 1874.

(3) On the basalt-glass of the Western Isles of Scotland. Q.J.G.S., Vol. XXXIX., p. 444.

occur only as the margins of basalt-dykes or in basalt-tuffs. In the Sandwich Islands, however, they are developed on a large scale in the crater of Kilauea.

APPENDIX TO GROUP F.

The most important change which affects the glassy rocks is that known as devitrification. By this process the older acid glasses have been frequently changed to *felsite*.

Palagonite is a substance formed by the alteration and hydration of basalt-glass.

GROUP G.

FRAGMENTAL VOLCANIC ROCKS.

Fragmental volcanic rocks are termed ashes, tuffs and agglomerates. No special nomenclature is required for rocks of this group. The character of the ash, tuff or agglomerate in any given case may be indicated by the term applied to the corresponding lava. We thus speak of liparite- or rhyolite-tuffs, andesite-tuffs, basalt-tuffs, &c.

APPENDIX TO GROUP G.

The fragmental rocks, like their massive representatives, are, of course, subject to change by surface and deep-seated agencies, and also by regional-metamorphism.

CHAPTER V.

Rocks of Group A.

THE first rock of this group which appears to have attracted general attention is the olivine-rock described by Lelièvre, in 1787. It was subsequently named Lherzolite by De La Méthérie[1] from the locality (Lake of Lherz) in the Pyrenees whence it was obtained. In 1862, Damour[2] showed that two-thirds of this rock consists of olivine, and that De la Méthérie, who regarded it as mainly composed of augite, had, therefore, been mistaken as to its composition. The remaining constituents are now known to be enstatite, chrome-diopside and chromite, picotite or pleonaste. According to the researches of Charpentier and Marrot the rock occurs in a liassic limestone which has been rendered crystalline by the intrusion of granite. Some discussion has taken place as to whether the rock is truly igneous or not, but the balance of evidence is decidedly in favour of the former view. Des Cloiseaux[3] has observed similar rocks in the Silurian limestone of Eaux Bonnes (Basses Pyrénées) and in the granitic region of Beyssac (Haute Loire).

One of the most remarkable eruptive olivine-rocks is that of the Dun Mountain in New Zealand described by Hochstetter.[4] The rock in question is composed of olivine and chrome-iron ore. It forms the top of a mountain 4,000 feet high, and stands in the closest relation with a huge sheet of serpentine, eight miles long and one or two broad, which is intrusive in mesozoic strata according to Hochstetter. This rock has been named *Dunite* by its discoverer.

Olivine-rocks frequently occur associated with the crystalline schists. Such rocks have been described by Sandberger,[5] Tschermak,[6] Kjerulf,[7] Pettersen,[8] Dathe,[9] Gümbel,[10] Axel Erdmann,[11] Brögger,[12]

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(1) Theorie de la Terre, Vol. II., p. 281.

(2) B.S.G., II. Ser., Vol. XIX., p. 413.

See Bonney. The Lherzolite of the Ariege. G.M. Decade II., Vol. IV., 1877, p. 59.

(3) B.S.M., Vol. XIX., p. 48.

(4) Z.D.G.G., 1864, p. 341. See also Reise seiner Majestät Fregatte Novara, Geologischer Theil, Band I., 218.

(5) N.J., 1866, p. 391.

(6) S.A.W., Vol. LVI., (1867).

(7) Verhandlg. d. Wiss., Gesell. Christiania, 1864.

(8) N.J., 1876, p. 613.

(9) N.J., 1876, p. 225.

(10) Geog. Beschr. d. Fichtelgebirges. Gotha, 1879, p. 148.

(11) N.J., 1849, p. 837.

(12) N.J., 1880, Band II., p. 187.

Reusch,[1] Cossa,[2] Julien[3] and others. With regard to these rocks the important question arises: Are they eruptive rocks of later date than the schists or must they be regarded as integral portions of the latter? The observations of Reusch and Brögger on the peridotites of Almeklovdal and other localities in Söndmöre (Norway) are especially interesting in relation to this question. Here the rocks consist of perfectly fresh olivine, green hornblende (smaragdite), chrome-iron ore and a few grains of brownish yellow enstatite. They possess a marked schistosity, recognisable in hand specimens, and also a banding due to variation in the relative proportions of the different constituents. Some of the bands consist almost entirely of olivine; others contain a large amount of smaragdite. The banding and schistosity are strictly parallel to each other and to the corresponding features in the surrounding gneissic series. These observations appear to prove conclusively that the rocks in question must be regarded as integral portions of the crystalline schists. They do not of course disprove the igneous origin of the peridotite, for it is now becoming evident that the crystalline schists are largely composed of igneous material.

In 1876 Dathe described a number of olivine rocks and serpentines from the granulitic region of Saxony. He divided the unaltered peridotites into two groups: *garnet-olivine rocks* and *enstatite-olivine rocks*. For the latter group Wadsworth has subsequently proposed the term *Saxonite*.

In 1869 Professor Tschermak[4] called attention to the existence of an olivine-rock which is intrusive in the Neocomian formations of Moravia and Silesia, and proposed for it the name of *Picrite*. This rock is of a dark green colour and either distinctly or finely crystalline. Olivine forms about one-half of the entire mass, and sometimes occurs in fairly large crystals thus giving the rock a porphyritic aspect. The groundmass contains hornblende, diallage and biotite, but the relative proportions of these constituents varies in different specimens. Magnetite is always and calcite often present. A little glass may sometimes be observed. In his definition of the term Tschermak lays special stress on the fact that about half the rock is composed of olivine.

In 1874 Professor Gümbel[5] described a rock of similar composition, occurring in the lower palaeozoic strata of the Fichtelgebirge under the name of Palaeopicrite. This rock was observed by him in no less than twenty localities. It is described as closely resembling a dark coloured diabase in appearance, and as consisting very largely of olivine; together with enstatite, chrome-diopside, augite and magnetite. Rocks of the same type are found associated with the Devono-carboniferous strata of Nassau.[6]

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(1) Das Grundgebirge im südlichen Söndmöre. Kristiania, 1877; and also N.J. (Ref.), 1880, Band II., p. 194.

(2) Ricerche chim. e. Microsc. &c. Turin, 1881; and N.J. (Ref.), 1882. Band II., p. 47.

(3) Proc. Boston Soc. Nat. Hist., XXII., 1882, p. 141.

(4) Die Porphyrgesteine Oesterreichs. Wien. 1869, p. 239.

(5) Die paläolithischen Eruptivgesteine des Fichtelgebirges. München, 1874.

(6) Oebbeke.—Ein Beitrag zur Kenntniss des Palaeopikrits. Inaug. Diss. Würzburg. 1877.

In 1880 Dr. A. Geikie [1] recognised the existence of rocks of this class in two localities near Edinburgh; at Blackburn, near Bathgate and in the island of Inchcolm. In both cases the rocks are associated with strata of carboniferous age. Felspar often occurs as an accessory constituent of the picrites, and by the gradual increase in the amount of this mineral the rocks of this class shade off into the olivine dolerites.

We have now to consider a further extension in the meaning of the term picrite. In 1881 Professor Bonney,[2] accepting the "Schillerfels" of Schreisheim in the Odenwald as a typical picrite on the authority of Professor Rosenbusch, called attention to a rock of similar character occurring as a boulder near Pen-y-Carnisiog in Anglesea. A microscopic examination proved that the dominant constituent of this rock was hornblende and not diallage, the mineral which was then regarded, on the authority of Professor Cohen, as the principal constituent of the Schreisheim rock. The most conspicuous macroscopic feature of the Pen-y-Carnisiog and Schreisheim rocks is the great abundance of conspicuous cleavage surfaces, often measuring two-thirds of an inch in length, of a black mineral. The reflection from these surfaces is, however, interrupted at numerous points by the presence of enclosures; a feature which is common to many basic and ultra-basic rocks, and which was specially mentioned by Streng [3] in 1862 as a characteristic of the Bastite rock of the Harz. Professor Pumpelly [4] called attention in 1878 to the same feature in the basic igneous rocks of the Lake Superior region, and proposed for it the term *lustre-mottling*. This term was adopted by Mr. Irving [5] in his detailed description of the same rocks. Mr. G. H. Williams has recently proposed the term *poicilitic* for the same feature; but as Pumpelly's term has priority and is moreover intelligible to everybody, there seems no sufficient reason for introducing a new term to the already over-burdened nomenclature of petrographical science. Lustre-mottling, then, is due to the enclosure of certain minerals in large irregular crystalline individuals belonging to one of the bisilicates; augite, enstatite or hornblende. In Scyelite it is due to corresponding enclosures in a uniaxial biotite. In basic rocks (*e.g.*, dolerite of Carreg-y-rimbill, Pwlhelli) the enclosed mineral is usually felspar; in the ultra-basic rocks (*e.g.*, Pen-y-Carnisiog rock) it is either olivine or its serpentinous pseudomorphs.

To return to the Pen-y-Carnisiog rock. Seeing that the dominant bisilicate was hornblende and that in this respect it differed from the true picrites, Professor Bonney proposed the name of hornblende-picrite. In the same paper Professor Bonney refers to a remarkable rock collected by Professor Sedgwick near Penarfynydd in the Lleyn peninsula, Caernarvonshire, as belonging to the same type. The slide in the Woodwardian

(1) Trans. Roy. Soc., Edin., Vol. XXIX. (1880), pp. 504-507.

(2) Q.J.G.S., Vol. XXXVII., p. 137.

(3) N. J., 1862, p. 533.

(4) Proc. Amer. Acad., Vol. XIII. (1878), p. 260.

(5) The copper-bearing rocks of Lake Superior. Monog., U.S. Geol. Survey, Vol. V., p. 1883.

Museum, Cambridge (see Fig. V., Plate VII.) shows that more than one-half of the rock is composed of olivine in the form of more or less rounded grains. The interspaces between the olivine grains are occupied as a rule either by a deep brown ("basaltic") hornblende or a nearly colourless pyroxene. The bisilicates, hornblende and pyroxene, polarise uniformly over large areas; but they do not show definite crystalline outline. Biotite and chloritic alteration products are sparingly present, but there is no definitely recognisable felspar. Here then we have a rock which answers to TSCHERMAK's definition of picrite, so far as the amount of olivine is concerned; a fact of some importance, as many of the rocks termed hornblende-picrite do not answer to this definition.

In subsequent papers Professor BONNEY has extended his term, hornblende-picrite, to rocks which occur as boulders in Anglesea and South Wales and also as dykes in Anglesea, the Lake District and the Lleyn peninsula. All these bear a close macroscopic resemblance to each other in consequence of the presence of numerous black cleavage surfaces which show lustre-mottling; but they vary considerably as to the relative proportions of the different constituents. Felspar comes in and sometimes plays a not inconsiderable part in their composition, either in the fresh or altered condition. Olivine and its pseudomorphs decrease in amount and, indeed, are as a rule less numerous than the definition of TSCHERMAK requires.

It was stated that the term hornblende-picrite was introduced on the assumption that the Schreisheim rock was a true picrite, *i.e.*, an olivine-diallage rock. Professor COHEN, who was responsible for this identification, has since shown that he was mistaken and that the supposed diallage is in reality hornblende.[1] He considers that this removes the rock in question from the picrite group altogether, and proposes the term *Hudsonite*, on the ground that a similar rock is extensively developed on the Hudson river. Mr. G. H. WILLIAMS points out [2] that this term has already been appropriated in America for a variety of pyroxene, and adds to the confusion by proposing Cortlandtite. In a still later paper, however, he lays no stress on the term Cortlandtite and simply calls the rocks hornblende-peridotites.[3]

The conclusions which the present writer would draw from this discussion on a question of nomenclature are that petrographers should definitely recognise that rocks are simply mineral aggregates without any well characterised individuality; and that they should content themselves in most cases with describing the varieties they meet with, and refrain from inventing a new "ite" for every local variation in composition and texture. Having regard to the nature of rocks it seems to him that less harm is often produced by the extension of old terms than by the invention of new ones.

If, then, we accept Professor BONNEY's term we may say that the picrites as a group may be divided into two sub-groups—the augite-picrites and the hornblende-picrites. The Inchcolm rock may be taken as the type of the

(1) N.J., 1885, Band I., p. 242.

(2) N.J., 1885, Band II., p. 175.

(3) Professor DANA had previously described allied rocks as chrysolitic hornblendite. G.M., 1881, p. 59.

former in this country, and the Penarfynydd rock as the type of the latter. In both augite and hornblende are present; but in the former the augite and in the latter the hornblende predominates. Felspar often occurs as an accessory constituent in the picrites, and varies in amount in different specimens taken from the same rock-mass. 'By an increase in the amount of the felspar and a decrease in the amount of olivine the augite-picrites shade off into the olivine-dolerites, and the hornblende-picrites into rocks which may be conveniently termed olivine-diorites.'[1]

In connection with this subject we may refer to a paper by Mr. WILLIAMS[2] on the "Peridotites near Peekskill." The great interest which attaches to these rocks lies in the fact that the mutual relations of the different varieties are well exposed and the rocks themselves remarkably fresh. The allied rocks in the British Isles are known only in boulders and a few more or less isolated exposures, and are usually much altered. The essential constituents of the basic and ultra-basic rocks of Peekskill are brown hornblende, augite (diallage), hypersthene, olivine, biotite and felspar. The accessory constituents are magnetite, magnetic pyrites and pleonaste. The felspathic shade into the non-felspathic rocks by the most insensible gradations, and the different varieties of the latter shade into each other in the same way. The olivine-bearing non-felspathic rocks are divided by Mr. WILLIAMS into two groups; the one characterised by the predominance of brown hornblende, the other by the predominance of augite or diallage. These two groups shade into each other and into the corresponding felspar-bearing rocks, the olivine-dolerites and the olivine-diorites, by the most insensible gradations.

Associated with the olivine-bearing non-felspathic rocks are other non-felspathic rocks from which olivine is entirely absent. These consist of two or more of the following minerals:—brown hornblende, augite (diallage), hypersthene and biotite. Every possible combination of these minerals appears to be represented in the rocks of this area; so that the number of varieties produced is practically infinite.

Here then we find relations similar to those described by Professor JUDD as occurring amongst the peridotites and gabbros of Rum and the Shiant Isles. Nothing can prove more conclusively the impropriety of burdening petrographical literature with names for every slight variety of rock than this evidence that in one and the same rock-mass the number of varieties is practically infinite. The whole rock-mass must be regarded as a mineral-aggregate and described accordingly.

With reference to the Peekskill rocks it may be remarked that in none of them does olivine appear to rise to anything like the proportion required by TSCHERMAK's definition of picrite and still less does it rise to the proportion found in the lherzolites, saxonites and dunites. Thus a variety

(1) Such for example as some of the diorites described by Mr. ALLPORT, Q.J.G.S., Vol. XXXV., p. 637. It must be remembered that these diorites are associated with rocks which are now known to be Cambrian and not Carboniferous, as was supposed at the time when Mr. ALLPORT's paper was written.

(2) A.J.S., 1886, p. 38.

of augite-picrite (augite-peridotite. WILLIAMS) from Montrose Point yielded only 15·34 per cent. of magnesia, whereas the lowest of the unaltered picrites of TSCHERMAK yielded 23·34 per cent.[1] The altered picrites contained much lower per-centages of magnesia; but then in these rocks there is direct evidence of the removal of magnesia, for the olivines are represented by pseudomorphs of calcium carbonate (sometimes over 40 per cent.), and a basic silicate containing lime, magnesia, alumina and alkalies.

With regard to the nomenclature of those rocks belonging to group A., which do not contain olivine there is little to be said. If we except the terms hornblendite and pyroxenite proposed by Professor DANA, special names have not yet been applied to members of this class. The only rocks of this class with which the present writer is acquainted in Britain occur in the Hebridean gneissic system of Sutherland; and they may possibily form an integral portion of that system. They have, however, a massive habit and are composed of hornblende, an intensely pleochroic pyroxene (amblystegite, JUDD) and biotite. They contain no trace of either olivine or felspar.

It is interesting to note that the rocks of Group A. are mostly granitic in texture. Limburgite and augitite are merely varieties of basalt in which the felspathic constituent has not individualised itself. In bulk analysis they agree with the basalts and not with the rocks of Group A.

CHARACTERS OF THE ROCK-FORMING MINERALS.

Olivine.—The most important mineral of this group of rocks is olivine. In the typical peridotites—the lherzolites, saxonites and dunites—it forms more than half of the entire mass of the rock. In dunite it forms, together with a small quantity of chrome iron ore, the whole; so that the rock itself yields an analysis agreeing substantially with that of the mineral. In the lherzolite of Lake Lherz it forms, according to DAMOUR, two-thirds of the entire mass. It occurs usually in the form of crystalline grains; sometimes, however, it shows an approach to definite crystalline form. As a rule it is nearly colourless in thin section, but sometimes it appears markedly yellow or yellowish-brown. As this is the colour of the iron-olivine (fayalite) of the eulysite of Tunaberg, it seems reasonable to infer that such varieties are rich in iron.[2]

Dr. OEBBEKE [3] has isolated and analysed the olivine of the picrite (palæopicrite) of the Schwarze Stein, Nassau; and thus proved that it contains a considerable amount of lime. It is intermediate in composition between normal olivine and the monticellite of Vesuvius.

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(1) Porphyrgesteine Österreichs, p. 244.

(2) See JUDD, Q.J.G.S., vol. XLI., p.

(3) Ein Beitrag zur Kenntniss des Palaeopikrits. Wurzburg 1877. Lime-olivine of the Schwarze Stein, SiO_2 = 42·53, MgO. = 35·68, CaO = 14·08, FeO = 6·48.

Owing to the absence of any well marked cleavages the cracks which are seen to traverse the olivine in thin sections are usually irregular. Traces of the brachypinacoidal (010) and more rarely of the macropinacoidal (100) cleavages may, however, sometimes be detected.[1] When viewed under the microscope the surface shows a roughness which is brought out in consequence of the high refractive power of the mineral. A difficulty sometimes arises in distinguishing between olivine and enstatite when both minerals are present in the granular form and when the latter does not possess the characteristic prismatic or pinacoidal cleavages. In such cases the colours produced under crossed nicols may be useful in effecting a diagnosis when a considerable number of sections of both minerals are available for comparison. The double refraction of olivine is much stronger than that of enstatite; so that the polarisation tints of the former occupy, on the average, a much higher position in NEWTON's scale than those of the latter, when the sections compared are of uniform thickness. A micro-chemical test is also available for distinguishing between the two minerals. By treating the uncovered slide with hot hydrochloric acid the olivine is decomposed with the separation of gelatinous silica while the enstatite remains unaffected.

Olivine often contains inclusions of chromite and magnetite and occurs itself as inclusions in the other minerals, especially hornblende and augite, (see Plates III., V., &c.). In some of the peridotites of the Western Isles of Scotland it contains the curious stellate and dendritic inclusions which are regarded by Professor JUDD as of secondary origin, and also minute liquid and gas cavities. The alteration of olivine by surface agencies—water, carbonic acid and oxygen—gives rise to serpentinous and other pseudomorphs. The alteration to serpentine is highly characteristic. It begins at the surface and along the irregular cracks which traverse the mineral.

Figure illustrating the partial conversion of olivine into serpentine.

(1) RENARD. Report on the Petrology of the Rocks of St. Paul. The Voyage of *H.M.S. Challenger*, Narrative, Vol. II., Appendix B., p. 9.

Fibrous serpentine is first produced and the axes of the fibres lie parallel to the surfaces from which the alteration has proceeded. Owing to parallelism in the arrangement of the individual fibres this serpentine gives a faint but definite reaction with polarised light, and extinguishes when the axes of the fibres lie parallel with the short axis of one of the nicols. The colour of the serpentine is either yellow, yellowish green or green. In most cases the formation of serpentine in this way is accompanied by the separation of iron oxides (ferric oxide, hydrated ferric oxide or magnetite) along the original cracks. If the process has stopped short of the entire alteration of the original mineral we then have granules of olivine lying in a net-work of serpentine, as in the accompanying figure, and the boundaries of the original olivine grains may be determined by observing the areas over which the isolated granules give simultaneous extinction or depolarise in a uniform manner.

If the process of serpentinisation is complete, so that no trace of the original olivine remains, it usually happens that the finally developed portions of serpentine, occupying the centres of the meshes, are isotropic.

It must not be supposed that serpentine is the final or only product of the alteration of olivine. Carbonates, silica and limonite are sometimes produced and represent a further stage of alteration. In the altered picrites, described by TSCHERMAK, the olivine crystals are represented by pseudomorphs composed of calcium carbonate (sometimes 40 p.c.) and a basic silicate containing alumina, lime, magnesia and alkalies. Here there must have been a great transference of material; magnesia and iron must have been removed, and lime, alumina and other substances introduced.

Another very interesting feature which sometimes arises in connection with the alteration of olivine is the formation of needles of a colourless hornblende (tremolite or grammatite). Such needles have been described under the name of *pilite* in a pseudomorph after olivine by F. BECKE.[1] They lie confusedly in a chloritic or serpentinous substance, and from the form of the pseudomorph there can be no doubt that they arise in connection with the alteration of olivine. Similar needles occur in the olivine pseudomorphs of the picrite of Clicker Tor, near Menheniot, Cornwall, and are referred to in the description of the figure of that rock (Fig. II., Plate II.) Precisely similar needles may sometimes be observed in the serpentinous matter of certain hornblende-picrites, as for example, in that of the St. David's boulder. In certain felspar-bearing rocks, either belonging to the picrites or more or less allied to them, [2] the olivines are seen to be surrounded by a zone of hornblende-needles which are arranged in a radial manner with reference to the surfaces of the olivine. These are regarded

(1) T.M.M. Neue Folge, Vol. V., p. 163.

(2) As for example the olivine-norites of Ölme in Sweden (TÖRNEBOHM. N.J., 1877, p. 383); the olivine-gabbro of Langenlois in Lower Austria (BECKE. T.M.M., 1882, Neue Folge, Vol. IV., pp. 355 and 450); the Troctolite of Belhelvie, Aberdeenshire (BONNEY. G.M., 1885, p. 444); the olivine-norite from Lake St. John, Prov., Quebec (ADAMS. Am. Naturalist, 1885, p. 1087); and the hornblende-picrite of Peekskill (WILLIAMS. A.J.S., 1886, p. 35).

by ROSENBUSCH [1] as arising in connection with the alteration of olivine. WILLIAMS, however, remarks that they occur at the junction of olivine and felspar, when both minerals are perfectly fresh; and he is inclined to regard them as due to processes connected with the consolidation of the rock. As these needles are unquestionably of secondary origin in the case of BECKE's *pilite* it seems natural to regard them as of like origin in the other cases.

Rhombic pyroxenes.—Under this head we include the minerals usually known as enstatite, bronzite and hypersthene. Professor ROSENBUSCH uses *enstatite* as the general name for the group; Professor TSCHERMAK, on the other hand, uses the term *bronzite*. The different varieties depend on the relative proportions of magnesia and ferrous oxide; and what is important is that there appears to be a perfectly continuous series from typical enstatite, a pure magnesian bisilicate ($Mg_2 SiO_4$), to the mineral with 33 per cent. of ferrous oxide for which VOM RATH proposed the term *amblystegite*. Professor JUDD uses the term enstatite for the group, and designates the different varieties as enstatite, ferriferous enstatite, highly ferriferous enstatite and excessively ferriferous enstatite. Professor TSCHERMAK [2] proposes that varieties with less than 5 per cent. of ferrous oxide should be termed *enstatite;* those containing from 5 to 15 per cent. *bronzite;* and those containing more than 15 per cent. *hypersthene*. Professor JUDD suggests that the latter group should be further subdivided; the term hypersthene or proto-hypersthene being applied to varieties containing between 15 and 25 per cent. of ferrous oxide and VOM RATH's term *amblystegite* to varieties containing more than the latter amount.

The optical and other physical properties of the rhombic pyroxenes have been shown by DES CLOISEAUX to stand in the closest relation to their chemical properties and to change continuously with the latter. Thus, as the percentage of ferrous oxide increases the negative optic axial angle diminishes from 133°8′ (in oil) in enstatite (proper) with 2·76 per cent. of ferrous oxide to 59°20′ in the amblystegite from Mt. Dore with 33·6 per cent. The pleochroism, hardness and specific gravity increase as the amount of iron increases. In the examination of thin sections colour and pleochroism are the only tests available for discriminating between the different varieties. Enstatite is practically colourless, and as a natural consequence devoid of pleochroism. The pleochroism of the other varieties is indicated in the following scheme.[3]

	BRONZITE.	HYPERSTHENE.	AMBLYSTEGITE.
a	*Yellowish*	*Reddish brown*	*Brilliant red*
β	*Yellowish*	*Reddish yellow*	*Red*
γ	*Greenish*	*Green*	*Bright green*

(1) Mik. Physiog., Band I., 1885, p. 413.

(2) Lehrbuch der Mineralogie, 1884, p. 436.

(3) It will be remembered that cross sections of the prism contain the a and β axes of elasticity; vertical sections contain the γ axis. a, β and γ represent the greatest, mean and least axes respectively.

In the typical peridotites the varieties present are enstatite and bronzite. These minerals usually occur without any definite crystalline outline. When cleavage cracks are present those parallel with the prism faces of the typical form, intersecting at angles of about 92° and 88°, may be readily detected in the unaltered mineral. Sections at right angles to these cleavage planes (cross sections of the prism) extinguish, in parallel rays of polarized light, when the short axes of the nicols bisect the angles formed by the traces of the cleavage planes, and give a positive bisectrix in convergent polarized light. (1) In addition to the prismatic cleavages one frequently observes a cleavage parallel to the brachypinacoid (010), and this is especially evident in the altered forms.

The commencement of alteration is seen in a fine striation parallel with the vertical axis. This striation frequently begins in the neighbourhood of transverse cracks which traverse the crystal and finally affects the entire mass. The development of this striation is accompanied by the formation of a perfect cleavage parallel to 010, and by the entire or partial obliteration of the prismatic cleavages which are usually so characteristic of the unaltered mineral. It is also accompanied by the addition of water and by a change in the ellipsoid of elasticity. In the unaltered or slightly enstatite or bronzite the optic axial plane lies in the plane of easiest pinacoidal cleavages (010); in the modified enstatite or bronzite (bastite) it lies in the plane of the macropinacoid (100). This furnishes a ready method of distinguishing bronzite with cleavage parallel to (010) from bastite. A cleavage flake of the latter mineral which may be detached with a pen-knife shows a negative bisectrix in convergent polarized light; whereas a corresponding flake of the former mineral gives no definite optic picture.(2)

The striation above referred to is due to a fine fibrous structure. The long axes of the fibres are approximately parallel with the vertical axis of the prism. A further stage of alteration is represented by the formation of serpentine, in which the fine fibrous structure is often more or less presented (see fig. 2, plate I.)

Monoclinic Pyroxenes.—Several varieties occur in this group of rocks. One of the most interesting is the green augite (chrome-diopside) of the lherzolites, the composition of which was first determined by DAMOUR. A similar augite occurs in the olivine-nodules in certain basalts, and in the picrite of the Schwarze Stein, near Dillgegend, in Nassau. Professor JUDD describes an augite which is bright green by reflected light, and pale green by transmitted light, in the picrites and rocks associated with the picrites on the flanks and summits of Halival, Haiskeval and Tralival, in the island of Rum. Dr. HEDDLE has analysed this green augite, and his analysis shows a close relation between this mineral and the

(1) Corresponding cross sections of a monoclinic pyroxene show an optic axis. Hence a ready method of distinguishing between these two minerals.

(2) The only other mineral that may be confused with bastite and bronzite is diallage. This may be instantly determined by the examination of a minute cleavage flake in convergent light, when an optic axis will be seen.

chrome-diopsides of various localities, although he does not appear to have detected chromium in this case. Possibly it was not sought for. The microscopic appearance of the mineral in question is represented in Fig. 1, Plate V.

	I.	II.	III.	IV.	V.
SiO_2 ...	53·63	50·443	52·92	54·25	50·537
Al_2O_3 ...	4·07	5·105	3·54	6·07	3·348
Cr_2O_3 ...	1·30	1·403	0·74	1·48	—
Fe_2O_3	8·50	9·696	4·75	7·49	1·338
FeO					4·423
MnO ...	—	—	—	—	0·230
CaO ...	20·37	14·629	19·99	17·75	21·419
MgO ...	12·48	17·418	17·43	13·63	17·050
K_2O ...	—	—	—	—	0·252
Na_2O ...	—	—	—	—	0·530
H_2O ...	—	—	—	—	0·706
	100·37	98·694	99·37	100·67	99·833

I. Chrome-diopside, from the Lake of Lherz, (Damour).[1]
II. Do. Schwarze Steine. Dillgegend, (Oebbeke).[2]
III. Do. Olivine-nodule. Kosakomer, (Farsky).[3]
IV Do. Lherzolite. Piedmont, (Cossa).[4]
V. Diopside. Halival, (Heddle).[5]

In the rocks of the picrite group we have several varieties of monoclinic pyroxene. These varieties are distinguished from each other under the microscope by colour, pleochroism, cleavages, and the extent to which crystalline form is developed. Some are perfectly colourless, others a pale yellow or brown, others brown, reddish-brown or violet. In some cases a change from a nearly colourless to a deeply coloured variety may be observed in one and the same individual.

In several varieties of the hornblende-picrites described by Professor Bonney a colourless mineral occurs, sometimes in the form of irregular grains and sometimes with perfectly definite crystalline form. In the case of a boulder from St. David's[6] the crystals show the brachypinacoids (010), the orthopinacoids (100), the faces of the prism (110), and the positive hemi-pyramid ($\bar{1}11$). The prismatic faces are less pronounced than the pinacoids in the zone of the vertical axis, and the terminal faces are sometimes ill-developed. Transverse sections show the usual prismatic cleavages, and give an optic axis in convergent light. Longitudinal sections with

(1) B.S.G., 2nd ser., XIX., p. 413.
(2) Ein Beitrag zur Kenntniss des Palaeopikits, Inaug. Diss. Würzburg. 1877.
(3) Verh. d.k.k. geol. Reichs. Wien, 1876, IX., p. 207.
(4) Quoted from Roth, Beiträge zur Petrographie, &c. Abh. d.k. preus. Akad. Wiss. Berlin, 1884, p. 13.
(5) Trans. Roy. Soc. Edin., vol. XXVIII. (1879), p. 479.
(6) Q.J.G.S., vol. XLI., p. 519.

parallel cleavage cracks and straight extinction, or, in other words, sections parallel to the orthopinacoid (100), also show an optic axis in convergent light. The maximum extinction for longitudinal sections is about 44°. The mineral is therefore a colourless monoclinic pyroxene. One striking feature is the very high order of the interference tints under crossed nicols. In this respect, and also in the rough appearance of the surfaces, it reminds one of olivine. This pyroxene occurs as inclusions in the brown hornblende.

Coloured varieties of augite occur in the picrites of the Western Isles of Scotland, and also in that of Inchcolm. In the last-mentioned rock the colour of the augite frequently varies in one and the same individual. Some portions are nearly colourless; others have a marked violet tint. The latter are pleochroic, and the character of the pleochroism appears to be similar to that of certain augites, rich in titanium, which have been described by KNOP. (1).

α and γ, yellowish

β, brown with a tinge of violet.

The augites of the Inchcolm rock sometimes show the "hour-glass" structure of Werwcke. The coloured augite of the picrites usually occurs in large irregular plates. It contains olivine and iron-ores as inclusions. When felspar is present in forms giving lath-shaped sections this mineral penetrates the augite in the manner characteristic of the ophitic olivine-dolerites. Indeed there can be no doubt that many of the picrites stand in close relation to the olivine-dolerites and pass into the latter in a perfectly gradual manner by an increase in the amount of felspar. The picrites as a group appear to stand in closer relations to the olivine-dolerites and olivine-diorites than to the typical peridotites.

Hornblende.—This mineral appears to be absent, as a rule, from the typical eruptive peridotites. A green hornblende (smaragdite), however, occurs in the olivine rocks which form an integral part of the crystalline schists. In the picrite group hornblende plays an important part and furnishes the basis for the division of this group into *picrites (proper)* or *augite-picrites*, and the rocks for which Professor BONNEY has proposed the term *hornblende-picrite*.

The hornblende of the picrites when viewed in thin sections may be brown, green or colourless. In some cases a gradual transition from the brown, through the green to the colourless variety may be observed in one and the same individual, and when this is the case the polarisation tints under crossed nicols are seen to rise in NEWTON'S scale as the natural colour of the mineral disappears. In these cases there can hardly be a doubt that the colourless variety has been produced from the coloured variety by a bleaching process. In other cases the boundary line between the colourless and deep brown hornblende is perfectly sharp, corresponding to a definite face of the hornblende crystal, whereas the external boundaries of

(1) Z.X., 1885, X., 58. See also ROSENBUSCH, Mik. Physiog., Band I., 1885, p. 437 and p. 443.

the colourless variety may be irregular or determined by accidents, such as the contiguity of two hornblende crystals.[1] Here we appear to have evidence that the colourless hornblende is entirely of secondary origin, and that it has been deposited on original hornblende exactly as the secondary quartz has been deposited on the grains of that mineral in many quartzites; that is in optical continuity with the original crystal or crystalline grain. That colourless hornblende arises in connection with the serpentinisation of olivine is proved by the phenomena described by BECKE; and we appear to have illustrations of the same feature in many of the British picrites. It seems advisable to say "in connection with" rather than "as a result of," because it is probable that the phenomenon is dependent on simultaneous changes in other minerals.

The brown hornblende is characteristic of the least altered rocks and is probably original, for it sometimes shows definite external forms in which not only the faces of the prism but also those of the clinopinacoid (010) are developed.

Cross sections of the prism in which the cleavage planes intersect at angles of about 124° and 56° change in colour, as the stage is rotated [2] above the polariser, from a rich brown (often a clove-brown) when the short diameter of the nicol bisects the acute angles formed by the intersections of the cleavage cracks, to a pale brown when the stage is rotated through 90°. Such sections are approximately parallel to the greatest and mean axes of elasticity (a and β), the former bisecting the obtuse, and the latter the acute angles of the parallelograms formed by the cleavage cracks. The colour for rays vibrating parallel to a is therefore pale brown, and that for rays vibrating parallel to β, brown or rich clove brown. Orthopinacoidal sections may be distinguished by parallel cleavage cracks and straight extinction. They contain the mean and least axes of elasticity, and show a feeble pleochroism, or else remain unchanged as the stage is rotated over the polariser.

a, *pale brown.*
β and γ, *deep brown.*

In the green varieties of hornblende which often occur in the same rock,

a, *pale brown or green.*
β and γ, *bluish green.*

It is interesting to note that the difference between the green and the brown hornblende in these rocks is most marked when the sections are viewed with rays vibrating parallel [3] to the β and γ axes. Crystals which present the most striking differences of colour when viewed under these

(1) See BONNEY. Q.J.G.S., Vol. XLI,, Plate XVI., Fig. 2.

(2) In testing for pleochroism the stage and not the polariser should always be rotated. Indeed, for ordinary petrographical work, it is advisable to keep the polariser always fixed in one position, and to remember the direction of the short axis.

(3) The rays of polarised light are assumed to be due to vibrations parallel to the short axis of the nicol.

circumstances sometimes appear identical when examined with light vibrating parallel to the *a* axis.

The hornblende of the rocks under consideration may occur in the form of large plates without any definite outline, exactly like the ophitic plates of augite, or as crystals showing definite form. The colourless variety may occur as fine needles (*pilite* of BECKE), or as good sized plates which have a silky appearance in consequence of their finely fibrous structrue.

The brown variety is sometimes found intimately intergrown with augite, and this relation will be described in detail when the Inchcolm rock is referred to. The two minerals appear to be related to each other in such a way that the vertical axis and plane of symmetry are common to both.

Biotite.—This mineral occurs as an accessory constituent of certain picrites. In the normal condition it is deeply coloured, and sections at right angles to the basal plane show a most intense pleochroism. In certain varieties of picrite it appears to have undergone a peculiar bleaching process, in virtue of which it has become almost colourless.[1] The characters of this nearly colourless biotite as it occurs in the curious rock from Achavarasdale Moor (Scyelite) have been described by Professor JUDD. It is the most conspicuous mineral when this rock is viewed in hand specimens, although by no means the most abundant. The fracture of the rock is largely determined by it, and large flat glistening surfaces, often measuring one square inch in area, are produced whenever the rock is broken. These surfaces have a pale bronzy colour and a submetallic lustre. The hardness of the mineral is about three of MOHS' scale. The specific gravity is 2·8. The mineral is almost infusible before the blow-pipe, and is scarcely acted upon by boiling hydrochloric or sulphuric acids. Its approximate chemical composition is :—

SiO_2	...	38·0
Al_2O_3	...	13·0
FeO (Fe_2O_3)	...	4·5
CaO	...	5·0
MgO	...	24·0
H_2O	...	6·5
K_2O and Na_2O (?)		3·0 (by diff.)

Thin flakes examined in convergent light show that the mineral is practically uniaxial, resembling in this respect a pale silvery biotite from Easton, Massachusetts, described by BLAKE.[2] When thin slices of the rock are examined under the microscope, sections of the mineral at right angles to the basal plane show a faint pleochroism of the type characteristic of biotite, and opaque inclusions, probably of a tabular form, are seen in certain parts of the mineral lying parallel with the planes of easy cleavage (see Fig. 2, Plate V.) These inclusions strongly suggest that the original mineral has been bleached by secondary actions ("schillerisation") involving

(1) JUDD. Q.J.G.S., Vol. XLI., p. 402.
See also WILLIAMS. A.J.S., 1886, p. 36.

(2) A.J.S., Vol. XII., (1851), p. 6.

the elimination of iron and the development of magnetite along the cleavage planes. Mr. Williams refers to a bleaching of biotite in his description of the rocks near Peekskill, N.Y.

The spinellids, magnetite and ilmenite.—In the typical peridotites—the dunites, saxonites and lherzolites—the minerals of the spinelle-group, chromite, picotite and pleonaste, commonly occur. The two former are indistinguishable under the microscope, and usually appear a deep brown colour. Sometimes the colour is so intense that the sections appear opaque except at their margins. Pleonaste is distinguished from chromite and picotite by its green colour when viewed in thin sections.

The magnetic and titaniferous iron ores occur in the picrites. The latter may frequently be recognised by the characteristic alteration product, leucoxene.

Felspar.—This mineral is entirely absent from the typical peridotites. Sometimes it occurs sparingly, however, in rocks which approach very closely to these types. In the picrite-group felspar frequently occurs as an accessory constituent. It usually shows the characteristic lamellar twinning on the albite-plan and sometimes also that of pericline. In all cases it appears, from the high extinction angles, to belong to one of the more basic species; labradorite, bytownite or anorthite. It may occur in forms which give lath-shaped sections, or as large irregular plates of secondary consolidation (Fig. 2, Plate III.) The felspar of the picrites appears to be peculiarly liable to alteration. In the Tertiary picrites it is usually fresh, but in the palæozoic picrites it is frequently represented by zeolitic pseudomorphs in which *analcime*, with its characteristic anomalous double-refraction, may sometimes be recognised. Natrolite also occurs. In the Menheniot picrite needles of colourless hornblende occur in the serpentinous pseudomorphs after olivine. It seems probable that the lime necessary for the formation of this secondary hornblende has been supplied by the decomposition of the felspar which unquestionably occurred in the original rock.

British Peridotites.

The rocks which have been so frequently referred to as the typical peridotites, the dunites, saxonites and lherzolites, are rarely found in Britain in the unaltered form. Ultra-basic rocks are largely developed in the Island of Rum and in the Shiant Isles to the North of Skye.[1] They are here associated with gabbros and dolerites. Some varieties consist almost wholly of olivine enclosing rounded grains of chromite and picotite; others consist mainly of olivine, augite and ferriferous enstatite, and must be classed therefore with the lherzolites. In the majority of cases, however, a certain amount of felspar appears to be present, and such rocks must be termed picrites.

(1) Judd Q.J.G.S., Vol. XLI., p. 389.

The first British rock definitely recognised as belonging to the picrite family is the augite-picrite of the Island of Inchcolm in the Firth of Forth. Specimens of this rock were collected by Mr. Ady, and described by Dr. A. Geikie[1] in 1880. The rock has since been described, and figured in Coles' "Studies in Microscopical Science."[2] It forms a conspicuous mural cliff of a rich brown colour and singularly barren aspect, on the east side of the landing place by the abbey.

In hand specimens the rock is seen to be moderately coarse in texture and dark green in colour on a freshly exposed surface. Grains of olivine and glistening cleavage surfaces of a black mica may be easily detected with a lens; also light coloured greenish patches which vary in abundance in different specimens, and which probably represent pseudomorphs after felspar. The examination of a large series of slides prepared from different portions of the mass shows that the rock is by no means uniform in composition. The constituents are olivine and its serpentinous pseudomorphs, augite, brown hornblende, biotite, felspar and pseudomorphs after felspar, iron-ores and apatite.

Olivine occurs in crystals and as grains. In some slides it is wonderfully fresh, but as a rule it is traversed by irregular anastomosing strings of honey yellow or bluish green (aquamarine) serpentine, the former colour predominating. In some specimens the olivine is wholly replaced by serpentine and, when this is the case, the honey yellow variety usually forms the main mass of the pseudomorph, passing over sometimes at the margin into the green variety which fills up the interstices between the other constituents of the rock.

The augite varies in tint from nearly colourless to a pale reddish brown. The tint frequently varies in one and the same individual, sometimes gradually and sometimes abruptly. In the latter case sections parallel to the vertical axis occasionally show the "hour-glass" structure (see Figs. 3 and 4, Plate V.), and sections more or less at right angles to this axis show a central kernel of nearly colourless augite with an outer zone of the coloured variety. The coloured variety is markedly pleochroic. It is difficult to define the pleochroism with precision from the material at the writer's disposal, but some idea of its character may be given by saying that sections approximately at right angles to the vertical axis of the prism change from a pale yellow when the vibration plane of the polariser lies parallel to the optic axial plane of the crystal, to a brownish violet when the stage is rotated through 90° (see Figs. 1 and 2, Plate VII.) This renders it highly probable that the pleochroism is the same as that of certain augites rich in titanium.

The augite of the Inchcolm rock sometimes shows an approach to definite crystalline form; but more commonly it is interfered with by the other constituents, including the felspar.

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(1) Trans. Roy. Soc. Edin., Vol. XXIX., p. 506.

(2) For June 10th and 17th, 1882. See also Judd. Q.J.G.S., Vol. XLI., p. 400.

The hornblende possesses the deep brown colour and strongly-marked pleochroism of the variety known as "basaltic" hornblende. α, pale yellowish brown; β and γ, rich clove brown. Sections approximately parallel to the orthopinacoid (100) show no pleochroism because they contain the β and γ axes.

The amount of hornblende varies in different specimens. In some it is almost as abundant as the augite; in others it is rare or altogether absent. The hornblende usually occurs on the margin of the augite as if crystals of the former mineral had been more or less completed by the latter. The boundary of the two minerals is often very irregular; tongues and flecks of hornblende penetrate the augite and are sometimes found completely isolated in the latter mineral near the zone of contact.

The two minerals have the vertical axis and plane of symmetry in common. The pleochroism of the augite is often seen to increase from the centre towards the margin (see Figs. 1 and 2, Plate VII.) and to approximate in character to the hornblende; nevertheless the final transition is abrupt. In some varieties of the Inchcolm rock detached crystals of basaltic hornblende occur in which the prism faces (110) and clinopinacoids (010) are sharply defined. Whenever the hornblende which is intergrown with the augite shows definite form the faces are those of the former and not those of the latter mineral.

The relations between augite and hornblende above described are common to many rocks more or less allied to that of Inchcolm, including certain picrites of Nassau,[1] the teschenites of Moravia,[2] Silesia and Portugal[3] and certain "greenstones" of Cornwall, as for example that of St. Minver.[4] Is it due to a paramorphic change of augite analogous to that which takes place when the green fibrous hornblende, known as *uralite*, is produced; or is it a case of the definite intergrowth of two mineral species? The fact that the brown hornblende here referred to shows the definite external form of that mineral at once shows that this is not analogous to "uralitisation." Is it, however, a case of what may be called "amphibolisation?" This appears to be the view of Macpherson, who suggests that the pleochroism of the augite may be due to the intercalation of ultra-microscopic lamellæ of hornblende. The general opinion of German petrographers is that we have here a case of the intergrowth of two definite mineral species, and this view has been greatly strengthened if not absolutely established by Rohrbach who has separated and analysed the two minerals from a variety of teschenite. He found that from a powder containing the two minerals a separation could be effected by means of a solution of bi-iodide of mercury and barium. The specific gravity of the hornblende was found to lie between 3·364 and 3·370; that of the augite between 3·376 and 3·421. The following are the analyses of the two minerals:

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(1) Rosenbusch. Mik. Phy., Band I., (1885), Plate XXI., Fig. I.

(2) Rohrbach. T.M.M., Neue Folge, Vol. VII., p. 24.

(3) Macpherson. B.S.G., 1882, p. 289.

(4) Phillips. Q.J.G.S., Vol. XXXIV., p. 478, and Plate XXII., Fig. V.

	AUGITE.	HORNBLENDE.[2]
SiO_2	44·22	36·91
Al_2O_3	10·49	16·30
Fe_2O_3	11·98	5·28
FeO	5·77	12·27
MgO	7·02	8·83
CaO	22·54	16·91
	102·02	96·50

It must be remembered that these two minerals have the same appearances and relations as those of the Inchcolm picrite. The analyses prove that they are essentially different in chemical composition.

The biotite does not appear to occur in well formed crystals. It is a deep brown in basal sections, and strongly pleochroic in sections parallel to the vertical axis. It is usually associated with secondary products and may itself be wholly or in part of secondary origin. ROHRBACH mentions the occurrence of biotite as a secondary product after augite in the teschenites.

Felspar varies in amount in different specimens, but is usually present only in very small quantity. It occurs in forms which give lath-shaped sections and also as irregular plates. Twin lamellation is sometimes preserved, and as the extinctions on both sides of the trace of the twinning plane are often very high the species probably approaches anorthite in composition. A striking feature in the felspar of this rock and also of those in a diabase from the neighbouring island of Car Craig is the frequency with which they are represented by zeolitic pseudomorphs. Whether the conditions have been peculiarly favourable to the decomposition of felspar; or whether the felspars have been peculiarly liable to alteration, is perhaps difficult to determine. The fact that they were probably allied to anorthite in composition suggests the latter view.

Titaniferous iron ore is present, and sometimes shows traces of alteration to leucoxene.

Apatite occurs sparingly. The secondary products are yellow and green serpentine, chlorite and zeolites.

Another variety of picrite allied to that of Inchcolm has been described by Dr. GEIKIE from Blackburn, near Bathgate. It forms a part of a lava stream "which was erupted and solidified at the surface during the accumulation of the older part of the carboniferous limestone series of West Lothian." In the Blackburn quarry a marked difference exists between the upper and lower portions of the mass. The former contains much felspar and is simply an altered olivine-dolerite (diabase); the latter contains very little felspar and is an altered picrite. It is traversed by "veins of serpentine and chrysotile, sometimes six inches thick and often streaked with calcite." This portion has been worked for many years as lakestone: a material which is used for the soles of ovens. Under the microscope this

(2) Alkalies were detected but not determined. A part of the deficiency is thus accounted for.

rock is seen to consist of serpentinous pseudomorphs after olivine, together with a pale brown or claret coloured augite and a very little felspar. Iron ores, pyrites and apatite are also present.

The rock of Clicker Tor, Menheniot, near Liskeard, Cornwall, presents many analogies with the Inchcolm rock, and must, at any rate, in part be classed with the picrites, as indeed was pointed out in the description of the Inchcolm rock in Cole's "Microscopical Studies." It consists principally of serpentinous pseudomorphs after olivine together with augite. The amount of felspar in the slides already examined is very small. The rock has already been described and figured (see Fig. 2, Plate II.) One interesting feature of this rock is the occurrence of secondary hornblende (tremolite) in the olivine pseudomorphs.

Many instances of picrite have been described by Professor JUDD as occurring in the Tertiary volcanic districts of Rum and the Shiant Isles.

This completes the list of localities in which augite-picrites have been already detected in the British Islands. The rocks stand in the closest relations to the picrites (palæo-picrites) of Nassau and the Fichtelgebirge. They are intimately related to the olivine-dolerites (diabases) into which they pass by the most insensible gradations.

We have now to consider the group of rocks for which Professor BONNEY has proposed the name hornblende-picrite. One of the most striking members of this group is the rock from Penarfynydd which was collected many years ago by Professor SEDGWICK. It is a medium grained, black or greenish black rock. Cleavage surfaces of a black mineral showing the characteristic lustre-mottling may be seen on a fractured surface. They are not however so conspicuous as in most of the rocks belonging to this group. Under the microscope olivine is seen to be by far the most abundant mineral; more than half the rock is composed of it. As a rule it is remarkably fresh; traversed only by narrow anastomosing strings of serpentine. Next in importance is a rich brown hornblende, which presents the characteristic pleochroism of this mineral. It occurs in large ophitic plates and plays the rôle of groundmass to the olivine of which the rock is so largely composed (see Fig. 5, Plate VII.) Enclosures of magnetite, probably of secondary origin, are common in the hornblende. Sometimes the cleavage cracks are sharply defined by dusty looking magnetite which has separated out along them. Although the prevailing colour of the hornblende is a rich brown, here and there small patches occur which are perfectly colourless. These patches sometimes extinguish at a slightly different angle from the main mass of the mineral. Professor BONNEY mentions the occurrence of colourless augite in the same rock.

Next in importance to the olivine and hornblende is a mineral "which occurs in radiated nests, tufted groups of fibres and associated plates, like a mica." This mineral presents somewhat exceptional characters. In sections at right angles to the perfect cleavage, some portions are seen to be green when viewed with rays vibrating parallel to the cleavage cracks, and a rich golden brown when viewed with rays vibrating at right angles to these cracks. These portions polarise in neutral tints. Other portions are a very pale

brown in the former position, and perfectly colourless in the latter. These give, under crossed nicols, a vivid chromatic polarisation. The striking contrast between the two varieties is that one is brown when viewed with light vibrating parallel to the cleavage cracks, the other shows a similar but deeper colour when viewed with light vibrating at right angles to these cracks.

The pleochroism of chlorite is thus defined by ROSENBUSCH; O (rays vibrating at right angles to the vertical axis), green. E (rays vibrating parallel with the vertical axis), yellow, red or brown. The pleochroism of the green variety above referred to agrees with this, and we therefore regard it as a chlorite. The pleochroism of the nearly colourless variety agrees with that of a bleached biotite. Iron oxides are plentifully scattered through the micaceous and chloritic aggregates, and are sometimes seen to be arranged parallel to the cleavage planes, as in the scyelite (see fig. 2, Plate V.) There is no original felspar, and it is very doubtful whether any traces of that mineral exist in the form of pseudomorphs.

The above specimen was collected by Professor SEDGWICK, and simply labelled "below Penarfynydd." Mr. TAWNEY[1] endeavoured to find the rock *in situ*, but was not altogether successful. The Geological Survey map shows Penarfynydd as the seaward termination of a long mass of greenstone extending north and south, for a distance of four miles. This mass was carefully investigated by Mr. TAWNEY, who detected in it two varieties; a greenish black rock, very rich in olivine and poor in felspar, and a brownish grey rock spotted with white, and containing a considerable amount of felspar. The former (olivine-diabase, TAWNEY) appeared to be intrusive in the latter (diabase, TAWNEY) and both were probably intrusive in rocks with Lower Arenig fossils.

Professor BONNEY has since pointed out[2] that in all probability Professor SEDGWICK's specimen is merely a variety of TAWNEY's "olivine-diabase," and has referred the latter rock to his group of hornblende-picrites. This rock shows marked lustre-mottling. It consists largely of olivine in rounded grains which occur as enclosures in augite, hornblende and felspar. Augite seems here to be somewhat more abundant than hornblende, so that the rock approaches the augite-picrites. It occurs in large sheets and smaller detached portions. Hornblende is present, and presents exactly the same features as that of the rock from Penarfynydd, which has already been described. Biotite is sparingly present. The felspar is mostly represented by zeolitic and other pseudomorphs, as in the Inchcolm rock.

Another variety of rock from the Penarfynydd ridge has been described by Mr. TAWNEY under the name of hornblendic diabase (see Fig. 2, Plate VIII.) It occurs near Careg Llefain. In the hand specimen it is blackish-brown to black, with cleavage surfaces of the bisilicates sometimes half an inch across. Basaltic hornblende and a colourless or nearly colourless pyroxene are the chief constituents, the former being the most abundant

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(1) Woodwardian Laboratory Notes, G.M. Decade II., Vol. VII., p. 208.

(2) Q.J.G.S., vol. XLI., p. 517.

and occurring in large ophitic plates. Both minerals pass over into green alteration products. Plagioclase occurs in the form of prisms and irregular plates of secondary consolidation. In the former condition it often penetrates and is sometimes completely enclosed within the bisilicates. Iron ores are very abundant. Olivine cannot be recognised, so that the rock has no place in the true picrites. As it appears, however, to be intimately associated with them it has seemed desirable to refer to it in this connection. If we regard the felspar as accessory this rock must be classed with that division of Group A, which is characterised by the absence of olivine.

The facts collected by Mr. TAWNEY prove very conclusively that we have in the greenstone ridge of Penarfynydd a mass of rock of varying lithological character. Some varieties consist very largely of olivine and approximate in character to the typical peridotites, others contain a smaller amount of olivine, and others again are without that mineral. Brown hornblende, augite and felspar, together with iron ores and apatite are the other constituents, and these also vary in amount in different portions of the mass.

We have now to consider those rocks for which the term hornblende-picrite was first proposed. It must be remembered that they differ from the original picrites of TSCHERMAK in containing a much smaller amount of olivine, and consequently a lower percentage of magnesia; 15 or 16 as against 23 per cent. Certain varieties have been described by Mr. TAWNEY [1] under the names *olivine-diabase* and *hornblende-diabase*, and by Mr. CLIFTON WARD [2] as *diorite*.

The term *hornblende-picrite* was introduced in 1881 by Professor BONNEY, under circumstances that have been already explained, and has since been extended to several rocks occurring as boulders or *in situ* in Wales and the Lake District. The most conspicuous macroscopic features of these rocks are a black or greenish black colour, lustre-mottling, and the absence or rarity of any definitely recognisable felspar. The constituents as seen under the microscopic are brown, green and colourless hornblende; colourless or nearly colourless augite; olivine or, more frequently, pseudomorphs after this mineral; felspar or secondary products after felspar; iron ores and apatite. The brown hornblende usually occurs in large ophitic plates and is the mineral which determines the lustre-mottling; sometimes it shows definite external form. The green variety sometimes appears to have been formed by a mere change in the colour of the brown, and sometimes it occurs in more or less independent needle-like (actinolitic) forms. The colourless variety sometimes appears to have been formed by the bleaching of the green variety, and sometimes unquestionably occurs as an independent mineral of secondary origin. Augite occurs in grains, plates and well formed crystals. Its characters have been already described. Biotite occurs sparingly. Fresh olivine is very rare. It has been recognised only in the

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(1) G.M. Decade II., Vol. VII., p. 211 and Vol. IX., p. 458.

(2) Geology of the Northern Port of the English Lake District. Mem. Geol. Survey. 1876, p. 36.

boulder at Porthlisky in the St. David's district. Pseudomorphs after olivine are abundant in most cases. All the rocks which have been at present examined give evidence of considerable alteration. Ill defined aggregates of secondary minerals commonly form a sort of groundmass, and render a precise description of the mineralogical composition of the rock impossible.

The rock of the Pen-y-Carnisiog [1] boulder is remarkable for the large size (sometimes two-thirds of an inch across) of its lustrous cleavage surfaces. It is composed of hornblende in the three conditions (see Fig. 1, Plate IV.; and Figs. 1 and 2, Plate VI.), colourless augite, pseudomorphs after olivine, iron-ores, brown mica, apatite and ill-defined aggregates of secondary products. In 1883 Professor Bonney described similar boulders from the neighbourhood of Ty Croes and on the shore at Porth Nobla. One of these has been analysed by Mr. J. A. Phillips, and another, that from the little cove, termed Pen-y-Cnwc, near Porth Nobla, has furnished the slide from which Fig. 1, Plate IV. is taken. All these rocks resemble the Pen-y-Carnisiog rock both macroscopically and microscopically. There are slight differences in the relative proportions of the different constituents and in the coarseness of the grain. In this paper Professor Bonney calls attention to the resemblance between his hornblende picrite and the rock of Little Knott, in Cumberland, termed *diorite* by Mr. Clifton Ward.

In 1885, Professor Bonney [2] gave a detailed description of the mode of occurrence and microscopic characters of the Little Knott rock. It is shown to vary in composition and texture. Sometimes it is fine grained; at others the hornblende crystals are quarter or even half an inch across. "In one part the bigger crystals are crowded together and tend to occur in vein-like bands." Felspar appears to be invariably present in the fresh or altered condition, and in some cases occurs in sufficient quantity to thoroughly justify the use of Mr. Ward's term. Petrographers will probably differ as to the name which should be given to the Little Knott rock. This, however, will be a matter of no consequence provided we recognise that the natural position of the rock is between the typical hornblende-picrites from which felspar is entirely absent and the "diorites" of the Chilvers Coton type described by Mr. Allport.[3] As these contained olivine they may be termed olivine-diorites.

In the same paper as that in which the Little Knott rock is described, Professor Bonney gives an account of certain dykes which occur at Caemawr, near Llanerchymedd, and at Pengorphwysfa, one and a-half miles east north-east of Amlwch (Anglesea). The Caemawr dykes are intrusive in Arenig strata according to Professor Hughes. The rocks of these dykes as usual vary in character, and especially in the amount of felspar which they

(1) Bonney. On a boulder of Hornblende Picrite near Pen-y-Carnisiog. Q.J.G.S., Vol. XXXVII., p. 137. Additional note on boulders of Hornblende Picrite. Q.J.G.S., Vol. XXXIX., p. 254.

(2) On the so-called Diorite of Little Knott (Cumberland) with further remarks on the occurrence of Picrites in Wales. Q.J.G.S., Vol. XLI., p. 511.

(3) Q.J.G.S., XXXV., p. 637.

contain. They are referred by Professor BONNEY to his hornblende-picrites; and so also is a rock occurring at Penyrhiwan, near Clynnog in the Lleyn Peninsula. The mode of occurrence of the latter rock has been carefully described by Mr. TAWNEY[1] who remarks with reference to it that "the dearth of felspar gives the rock an outward resemblance to picrite, which is also kept up by the enclosures which break the reflection of light from the cleavage planes of the hornblende; but we have been unable to determine any olivine pseudomorphs among these." It must be remembered that lustre-mottling, taken by itself, is of no use as a diagnostic character of the hornblende-picrites. It is beautifully shown in many ophitic dolerites (diabases), as for instance in that of the Gimblet rock (Carreg-y-rimbill) Pwlhelli. In such cases the cleavage faces are those of augite, and the mottling is due to inclusions of felspar.

The only other instance of hornblende-picrite that we have to notice occurs as a boulder at Porthlisky, St. David's. It was recognised by Dr. HICKS and has been described by Professor BONNEY in the last-mentioned paper. The rock is greenish in colour and shows lustre-mottling in a most striking manner, some of the hornblende crystals measuring three-fourths of an inch across. In composition it bears the closest relation to the Pen-y-Carnisiog boulder and other rocks of that type.

It differs, however, in one or two important particulars. Here and there portions of the rock appear to have escaped alteration, and in such portions perfectly fresh olivine, with dendritic and plumose magnetite in the irregular cracks, and unaltered plagioclase which plays the rôle of groundmass (see Fig. 2, Plate III.) may be detected. Another striking feature is the occurrence of a nearly colourless pyroxene in well-formed crystals. A colourless pyroxene is not uncommon in the hornblende-picrites but it usually occurs in more or less irregular grains and plates. Here it is well crystallised. It occurs as inclusions in the brown hornblende and amongst the secondary products—serpentine, tremolite, &c.—which make up a not inconsiderable portion of what may be termed the groundmass of the rock.

In connection with the hornblende-picrites, we have to notice the remarkable rock from Achavarasdale Moor, Caithness, which has been referred to by Professor HEDDLE[2] and described in detail by Professor JUDD[3] as a mica-hornblende-picrite (Scyelite). It forms a boss nine yards long, seven and a-half yards broad and ten feet high and is surrounded by disintegrated fragments of similar material, so that its relation to the surrounding rock cannot be observed. A fractured surface shows a number of flat planes, often measuring one square inch or more in area. These planes have a bronzy yellow colour and a submetallic lustre. They meet each other at various angles; but there is no constancy in these angles.

The rock is composed of altered biotite, hornblende, serpentinous pseudomorphs after olivine and possibly after enstatite, and magnetite. The

(1) G.M. Decade II., Vol. IX., p. 458.

(2) M.M., Vol. V., p. 260.

(3) Q.J.G.S., Vol. XLI., p. 401.

characters of the mica have been already described. The hornblende is pale green by transmitted light, and shows a pleochroism which is characteristic but not strongly marked. Sometimes it contains tabular inclusions, which have suggested to Professor JUDD that it may have been derived from diallage. Serpentinous pseudomorphs occur in the hornblende, and their characters are thus described by Professor JUDD: "Examined with high powers of the microscope, this serpentine is seen to be filled with black and brown enclosures, some rod-like and stellate in form, others of a tabular character. Sometimes these inclusions are arranged in one set of parallel planes only; in other cases they lie in two sets of planes intersecting one another. There can be no doubt that much of this serpentine is pseudomorphous after olivine; but some of it may replace enstatite." The relative proportions of the different materials have been estimated by making a number of drawings with the camera lucida and then cutting out and weighing the portions which represent the different minerals. The result obtained by Professor JUDD is as follows:—

Hornblende	58·5 per cent.
Serpentine	22·0 „
Altered mica	18·5 „
Magnetite and accessory constituents	1·0 „

The chemical composition of the rock is given in the following table of analyses.

ANALYSES OF BRITISH AND FOREIGN ROCKS BELONGING TO GROUP A.

	I.	II.	III.	IV.	V.
SiO_2	42·80	43·84	45·68	39·103	40·79
Al_2O_3	—	1·14	6·28	4·940	10·41
Cr_2O_3	—	0·42	0·26	·446	—
Fe_2O_3	9·40	8·76	9·12	4·315	3·52
FeO				11·441	6.39
CaO	—	1·71	2·15	3·951	8·48
MgO	47·38	44·33	34·76	29·176	23·34
MnO	—	·12	—	·276	—
K_2O	—	—	—	tr.	0·71
Na_2O		—	—	—	1·71
H_2O and CO_2	·57	1·06	1·21	5·669	4·04
	100·15	101·38	99·46	99·317	99·39
Sp. Gr.	3·295	3·287	3·269	2·93	2·960

	VI.	VII.	VIII.	IX.	X.
SiO_2 ...	42·85	37·8	42·10	42·94	41·44
Al_2O_3 ...	10·42	9·7	3·28	10·87	6·63
Cr_2O_3 ...	—	—	—	—	—
Fe_2O_3 ...	6·27	3·4	8·27	3·47	13·87
FeO ...	6·86	7·0	2·13	10·14	6·30
CaO ...	11·84	4·1	3·77	9·07	7·20
MgO ...	9·01	22·9	30·65	16·32	18·42
MnO ...	—	—	·70	tr.	—
K_2O ...	1·61	·8	1·90	0·15	0·93
Na_2O ...	1·65			0·30	0·24
H_2O and CO_2	8·58	14·0	7·73	6·09	5·60
	99·09	99·7	100·53	99·95	100·63
Sp. Gr.	—	2·81	2·82	2·88	—

I. Dunite. Dun Mountain, New Zealand. Composed of olivine with chromite or picotite. Reise seiner Majestät Fregatte Novara. Geol. Theil., Band I., p. 218.

II. Olivine-enstatite-rock (Saxonite). St. Paul's Rocks. Voyage of *H.M.S. Challenger*. Narrative, Vol. II., Appendix B. Analysis by Sipöcz. Contains also 0·51 NiO.

III. Olivine-enstatite-augite-rock (Lherzolite). Baldissero. Monte Rossi, Piedmont. Composed of olivine (67 per cent.) enstatite, chrome-diopside, picotite and pyrite. Cossa; quoted from Roth's Beiträge zur Petrographie, &c., Berlin, 1884.

IV Olivine-augite-rock. Picrite (Palæopicrite). Schwarze Stein, Dillgegend, Nassau. Contains also ·162 NiO and traces of Cu, Bi, Co. S, and P_2O_5. Oebbeke; Ein Beitrag zur Kenntniss des Palæopikrits. Inaug. Diss. Wurzburg, 1877.

V. Picrite (Tschermak) Gumbelberge. Olivine and diallage in a ground-mass composed of diallage, biotite, magnetite, calcite, microlites and glass. Olivine more or less serpentinised. This is one of the original picrites. Tschermak; Porphyrgesteine Österreichs. Wien, 1869, p. 247.

VI. Altered Picrite. Söhle. This rock contains 5·88 of CO_2. The olivine is represented by pseudomorphs of calcite and a basic silicate containing lime, magnesia, alumina and alkalies. The alteration has been accompanied by the removal of magnesia and the introduction of lime. Tschermak; Porphyrgesteine, &c., p. 252.

VII. Altered Picrite (Palæopicrite). Inchcolm. Judd; Q.J.G.S., Vol. XLI., p. 400. Analysis by Waller.

VIII. Scyelite. Judd; Q.J.G.S., Vol. XLI., p. 402. Analysis by H. R. Mill.

IX. Hornblende-picrite. Boulder near Ty Croes, Anglesea. Bonney. Q.J.G.S., Vol. XXXIX., p. 256. Analysis by J. A. Phillips.

X. Hornblende-picrite, Schriesheim. Quoted from last-mentioned paper.

CHAPTER VI.

ON SERPENTINE.

Historical Sketch.

IF we were to adhere strictly to our plan of arrangement we should refer in this connection only to those serpentines which can be proved to have been produced by the alteration of eruptive rocks belonging to Group A. Having regard to the difficult nature of the subject and to the imperfect character of our knowledge, it seems desirable, however, in this brief historical sketch not to limit ourselves rigidly to the serpentines which have been definitely proved to be of eruptive origin.

Serpentine occurs as a mineral and as a rock. The mineral serpentine $3\,(Mg\ Fe)\,O.\ 2\,Si\,O_2.\ 2\,H_2O.$, whenever it shows definite external form appears to be a pseudomorph. In 1835, Quenstedt [1] described the so-called serpentine crystals of Snarum, in Norway, and arrived at the conclusion that they have been produced by the alteration of olivine. His view as to their origin met with some opposition from Sheerer, Hermann and others, but it has been fully established by G. Rose [2] and Volger,[3] as well as by a host of more recent observers.

These crystals frequently contain unaltered olivine. The relation between the serpentine and the olivine has been well described by G. Rose, and his description will apply without any alteration to the appearances seen in microscopic sections of altered olivine-bearing rocks. The original olivine is surrounded by a border of serpentine, and this substance also occurs on either side of the cracks which traversed the original crystals. As a result we have kernels of olivine embedded in an irregular net-work of serpentine. The following analyses by Helland illustrate the nature of the change.

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(1) P.A. Vol. XXXVI. p. 370.

(2) P.A., Vol. LXXXII., p. 511. (1851).

(3) Entwickelungs geschichte der Talk-glimmer Familie, p. 283.

	I.	II.	III.
SiO_2	41·32	42·72	43·48
Al_2O_3	0·28	0·06	
FeO	2·39	2·25	
CrO	0·05	tr.	
MgO	54·69	42·52	43,48
H_2O	0·20	13·39	13·04
	98·93	100·94	100·00

I. Olivine. Snarum.
II. Serpentine derived from the above.
III. Theoretical composition of serpentine.

Of the two molecules of water which are present in serpentine, one is driven off at a lower temperature than the other, and hence RAMMELSBERG [1] concludes that the molecular constitution of serpentine may be expressed as follows: $H_2 Mg_3 Si_2 O_8 + H_2O$.

The general question of the formation of serpentine by the alteration of the magnesian and ferro-magnesian silicates, has been discussed in an able memoir by J. ROTH.—Über den Serpentin und die genetischen Beziehungen desselben.[2] In this memoir the author points out that the ordinary agents of weathering—water, carbonic acid and oxygen—are powerless to remove alumina; and he draws the general conclusion that if a non-alumninous silicate rock occurs as an alteration product, it must arise from the modification of an original rock free from alumina. Powerful chemical reagents, such as sulphuric acid which may arise from the oxidation of pyrites, capable of removing alumina,[3] would of course also remove the other bases including the magnesia necessary for the formation of serpentine. Now the *rock*, serpentine, is practically non-aluminous, and it is also in most if not in all cases, unquestionably an alteration product. It becomes important therefore to consider what common rock-forming minerals are capable of yielding serpentine. The above considerations point to the conclusion that these minerals are olivine, the rhombic pyroxenes, diallage and non-aluminous hornblende and augite. According to the author the process of making serpentine commences by the taking up of water and by the oxidation of the iron if the infiltrating water contains free oxygen. It proceeds by the removal of bases, especially lime if present, mainly as carbonates; and a portion of the precipitated and therefore soluble silica. If we take the case of olivine; then assuming that no change of volume occurs,

(1) Z.D.G.G., Vol. XXI., p. 98 (1869).

(2) Abh. d. k. Akad. d. Wiss. Berlin. 1869.

(3) A spring at Trefriw, between Conway and Llanwrst contains ·136 p.c. of sulphate of aluminum. The removal of alumina is illustrated by the occurence of pseudomorphs of quartz after felspar. (See Blake Q.J.G.S., Vol. XL., p. 308)

from 5 molecules	=	10 MgO	+	5 SiO_2		
by removing		4 MgO	+	1 SiO		
and adding 4 H_2O we have		6 MgO	+	4 SiO_2	+	4 H_2O

or in other words, two molecules of serpentine.

Roth then proceeds to discuss the formation of serpentine from each of the minerals which have been regarded as capable of yielding it, and shows very clearly that his general conclusions are borne out by an examination of established facts. One of the most interesting cases, inasmuch as it involves the removal of a large amount of material, is that of the formation of serpentine from a non-aluminous lime-magnesia-iron pyroxene occurring at Sala, in Sweden. The following row of analyses by H. Rose, Svanberg and Lychnell serve to illustrate this change. In the altered forms the water has been deducted and the analysis calculated to 100.

	I.	II.	III.	IV.	V.
SiO_2	54·86	59·66	63·33	56·16	48·77
CaO	23·57	11·55	5·18	0·88	—
MgO	16·49	22·88	26·31	33·96	48.88
FeO	4·44	5·44	4·36	7·74	—
MnO	—	—	0·82	—	—
Al_2O_3	0·21	0 47	—	1·26	2·35
	99·57	100·00	100·00	100·00	100·00

I. Fresh pyroxene (Salite). (H. Rose).
II. Altered do. with 3·12 p.c. H_2O. (H. Rose).
III. Do. do. „ 4·52 „ (H. Rose).
IV. Do. do. „ 9·83 „ (Svanberg).
V. Serpentine with 12·33 (Lychnell).

The change revealed by these analyses can be explained on the assumption that SiO_2 and CaO are removed. Roth, however, suggests the possibility that some MgO may have been added. At any rate, the formation of serpentine in connection with the alteration of a monoclinic pyroxene appears to be established.

The formation of serpentine by the alteration and hydration of ferromagnesian and magnesian silicates is therefore proved beyond all question; but does this substance arise in any other way? Its frequent association with crystalline limestones and dolomites in the ophicalcites has led certain observers [1] to regard it as arising from the alteration of rocks rich in magnesian carbonate, and by chemical reactions in which the latter substance is involved. Such a mode of origin, however, does not appear to be definitely established; for the limestones and dolomites in question are often extremely rich in silicates (malacolite, tremolite, &c.), from which serpentine may have been derived in the ordinary way. Dr. Sterry Hunt

(1) Volger. Entwickelungs geschichte der Talk-glimmer Familie.

has speculated on the possibility of certain serpentines having been deposited as such from the primordial ocean along with the crystalline schists with which they are often so intimately associated.

The formation of serpentine in connection with the alteration of felspar has been described by several observers.[1] The following chemical reactions established by BISCHOF show the possibility of such an event:—

(1) Silicate of lime is decomposed by magnesium sulphate or chloride; with the formation of magnesium silicate and calcium sulphate or chloride.[2]

(2) Aluminium silicate is decomposed by magnesium sulphate or chloride; with the formation of magnesium silicate and aluminium sulphate or chloride.[3]

(3) Calcium silicate and magnesium bicarbonate form magnesium silicate and calcium bicarbonate.[4]

(4) Potassium silicate and magnesium bicarbonate form magnesium silicate and potassium carbonate.[5]

It will be observed that in all these cases the reactions are of a complicated character. The production of serpentine from felspar by the simple action of water charged with carbonic acid and oxygen is an impossibility, for alumina as well as lime must be removed. Such a production does not appear impossible if we bring to our aid solutions of magnesium chlorides and sulphates. If, however, instead of considering chemical possibilities, we turn to nature and ask if there be any evidence of the development of serpentine on a large scale in connection with the alteration of felspar we appear to meet with a negative answer. The substance analysed by Professor HEDDLE [6] from the gabbro of Beauty Hill, Aberdeen, contains 12·444 p.c. of alumina and is, as indeed he himself points out, a massive variety of pennine (pseudophite) and not a true serpentine.

So far we have been considering serpentine from a chemical and mineralogical, rather than from a geological standpoint. We have now to go back in time and describe the important work of SANDBERGER and TSCHERMAK on the origin of serpentine rock-masses.

In 1866, SANDBERGER [7] arrived at the conclusion that many serpentines have been produced by the alteration of olivine-rocks (peridotites). He observed in the serpentine of several localities nodules of olivine-rock which were not bounded by any hard and fast lines, but which passed gradually into the surrounding mass. Seeing that the formation of serpentine from olivine had been definitely established, he concluded that these transitions in space indicated corresponding transitions in time, and regarded the olivine-

(1) See HEDDLE. Trans. Royal Soc. Edin. 1879. Vol. XXVIII., p. 544.
(2) BISCHOF. Chemical and Physical Geology. Eng. Edit. Vol. II., pp. 66 and 67.
(3) Ibid. p. 69.
(4) Ibid. Vol. I., p. 13.
(5) Ibid. Vol. II., p. 69.
(6) Trans. Royal Soc. Edin. 1879. Vol. XXVIII., p. 543.
(7) N.J., 1866, p. 391.

rock as the mother-rock from which the serpentine had been produced. He especially insisted on the importance of the accessory minerals as throwing light on the origin of any particular mass of serpentine. Thus one or more of the minerals, chromite, picotite, pleonaste, chrome-diopside, enstatite and pyrope, are found in the typical peridotites. The occurrence of any of these minerals in a serpentine is therefore strong evidence that it has been produced by the alteration of an olivine rock.

In 1867, TSCHERMAK [1] published two papers in which he confirmed and extended the conclusions of SANDBERGER. To understand fully the importance of TSCHERMAK's work, it must be remembered that at the time it was executed the opinion that serpentine might be produced by the alteration of almost any rock was generally held. Gabbro, eklogite, diabase, diorite, granulite and even granite were supposed to be capable of transmutation into serpentine. This view, advocated by BISCHOF [2] and G. ROSE, [3] was based on the fact that gradual transitions from these rocks to serpentine might be observed in the field. Now a transition from one rock to another in space may or may not imply a corresponding transition in time. It has been shown in the present work that one and the same rock-mass may vary considerably in its mineralogical composition. An olivine-rock without felspar may pass gradually into a rock containing a considerable amount of felspar and comparatively little olivine. If the olivine in such a rock-mass becomes serpentinised, then we may have a gradual passage in space from serpentine to a felspathic rock; but such a transition in no way implies that the serpentine has been produced by the alteration of a felspar-bearing rock. In the first paper TSCHERMAK proved that olivine is much more widely distributed as a rock-forming constituent than the earlier observers had supposed; in the second he discussed the relations of serpentine to eklogite, granulite and gabbro, and showed clearly that, in the cases which had come under his notice, the serpentine had originated in consequence of the alteration of olivine; and that the observed transition in space was merely due to an original variation in the composition of the rock-mass.

The work of SANDBERGER and TSCHERMAK produced a strong reaction against the extreme views of BISCHOF and ROSE, and petrographers naturally asked themselves whether any of the serpentine rock-masses had been produced in any other way than by the alteration of olivine-rocks. That serpentine as a mineral could be produced by the alteration of enstatite, diallage, and non-aluminous augite and hornblende was admitted. But could serpentine as a rock be produced in the same way?

The application of the microscope to the study of serpentine, appears to have been first made by WEBSKY [4]; but it was not until TSCHERMAK took up the question that any important advance was made in our knowledge of the minute structure of the rock. TSCHERMAK showed that the serpentine derived

(1) Über die Verbreitung des Olivin in den Felsarten. S.A.W., Vol. LVI., p. 261.
Über Serpentinbildung. Same Vol., p. 283.

(2) Chemical and Physical Geology. Eng. Edit. Vol. II., p. 415.

(3) P.A., LXXXII., p. 511.

(4) Z.D.G.G. 1858, p. 277.

from olivine possesses a characteristic structure (maschen-structur) which, in most cases, enables one to speak confidently as to its origin, even when every portion of the original substance of the olivine has disappeared. The serpentinisation of the olivine proceeds along the irregular cracks which traverse the mineral. Water obtains access to the interior by means of these cracks and, in olivines containing a considerable amount of iron, the oxides of this metal—magnetite and ferric oxide—are formed along them. When the serpentinising process is complete these oxides remain, and thus define by their distribution the original structure of the olivine. Even when iron oxides are not formed in this way the micro-structure of the serpentine substance itself stands related to the original structure of the olivine, and leaves no doubt as to the origin of the rock. The irregularity of the network here referred to is of course due to the fact that olivine does not possess strongly marked cleavages. Now the other minerals from which serpentine may be produced possess well marked cleavages, and it might naturally be expected, even anterior to observation, that evidence of this would remain in the resulting serpentine.

In 1871 Drasche[1] communicated a paper "Über Serpentin und serpentinähnliche Gesteine." In this paper he showed that serpentines which bear the closest possible resemblence to each other so far as composition is concerned differ considerably in micro-structure. On the one hand, there are the serpentines with "maschenstructur"—the true serpentines of the author—and on the other, rocks yielding a true serpentine analysis, but having a totally different micro-structure—the "serpentinähnliche gesteine." Many instances of true serpentines are described by the author, but as they do not differ in any essential respect from the similar serpentines described by TSCHERMAK, nothing need be said about them in this historical sketch. As a type of the "serpentinähnliche gesteine" the author takes a rock from Windisch Matrey, in the Northern Tyrol, which is conformably interstratified with a calcareous mica-schist. This rock varies considerably in character and is often traversed by veins of calcite, asbestus and chrysotile. One specimen, of a light olive green colour, flecked with yellowish brown specks, was examined both chemically and microscopically. It possessed a bluish lustre and an uneven fracture. Here and there green scales of a mineral with one well-marked cleavage could be detected, and as flakes of this mineral when examined in convergent polarised light showed an optic axis, it was identified as diallage. The following analysis proves that the rock is a serpentine so far as composition is concerned; but that it is not a normal serpentine is proved by the fact that it is not acted upon by hydrochloric acid.

(1) T.M.M. 1871, p. 1.

SiO_2	41·57
Al_2O_3	0·67
Fe_2O_3	2·63
FeO	5·31
CaO	1·22
MgO	36·66
CO_2	0·51
Loss	11·88
	100·45

Microscopic examination showed that the rock is mainly composed of a mineral giving either lath-shaped sections or else sections in the form of irregular plates. The former gave straight extinction and showed a fine striation indicating a perfect cleavage of the mica type, parallel with the broad flat surfaces. They were sometimes seen to be distributed irregularly and at others to be arranged in two parallel series intersecting approximately at an angle of 90°. These observations show that the mineral in question occurs in irregular plates and possesses a strongly marked basal cleavage. It has the hardness of talc. The other constituents of the rock are magnetite, in the form of grains, and the diallage already referred to.

Rocks of a similar character are described from other localities in the Alps. Drasche's researches leave some doubt as to the true character of the talc-like mineral and also as to the true nature of the rock by the alteration of which the serpentine has been produced. It will presently be shown that the later researches of Hussak supplement those of Drasche, and furnish a solution of the problem relating to the origin of these rocks.

In 1877, Professor Bonney [1] gave a detailed account of the field relations and microscopic structure of the serpentines of the Lizard, and proved that they are altered olivine-rocks allied to the Lherzolite of Ariege [2] of which he published a description in the same year. He has since investigated other British serpentines, but, as a detailed account of his researches will be given when the rocks are described it is unnecessary to do more than to refer to them in this connection.

We have now to notice a paper by Weigand on the serpentines of the Vosges, which appeared in 1875.[3] Many of these serpentines, as for instance those of Bonhomme and Starkenbach, are shown by their microscopic structures and accessory minerals to have been formed from olivine-rocks. One, however, viz., that of the Rauenthal, is exceptional and deserves a more careful description on our part. The rock in question occurs in a gneissic series, certain bands of which are rich in mica and hornblende. By the increase in the latter mineral the rock passes into an amphibolite. The serpentine is associated with the latter rock. As the serpentine is approached the hornblende of the amphibolite becomes lighter in colour and shows a platy structure. The cleavage faces assume a sub-metallic lustre. Small and

(1) Q.J.G.S., vol. XXXIII., p. 884.
(2) G.M. 1877. p. 59.
(3) T.M.M..; 1875, p. 183.

large shreds of serpentine make their appearance, and the boundaries of these are not sharply separated from the matrix in which they lie. By the increase in the serpentinous portions the amphibolite passes gradually into a rock which may fairly be called a serpentine, [1] though it differs in macroscopic habit from the normal olivine-serpentines. This serpentine is dark in colour and often shows a more or less schistose structure. It is crowded with large irregular silvery scales which are sometimes aggregated into definite bands, and sometimes scattered irregularly through the dark ground mass. Cleavage flakes of the silvery minerals show in convergent polarised light a black cross, the arms of which do not open out into hyperbolæ as the stage is rotated. The mineral is therefore uniaxial. With regard to the serpentine the important questions which arise are these. Has it been formed by the alteration of hornblende or did the amphibolite originally pass into an olivine-rock? Does the transition in space correspond to a transition in time, or have we here another case similar to those described by TSCHERMAK?

Microscopic examination shows that the rock differs markedly from normal olivine serpentine. It consists of a transparent green or colourless substance, in which the irregular "maschenstructur," due to the separation of iron oxides along the original cracks of olivine, is absent. Where the serpentinising process is complete this substance splits up, under crossed nicols, into doubly-refracting bands and isotropic portions. The disposition of the former often gives rise to a structure which reminds one of lattice-work, and strongly suggests cross-sections of a hornblende prism. The central portions of the lattice-meshes are either occupied by isotropic serpentine or by kernels of a vividly-polarising mineral. In the latter case the adjacent grains give simultaneous extinction, thus proving that their present isolation is merely the result of the development of serpentine from the original crystal which they represent. What was this crystal? As we have already seen, the lattice-structure strongly suggests that it was hornblende. This suggestion is reduced to a certainty by the examination of sections in which the two series of serpentine bands are seen to be parallel to each other. In such sections the maximum extinction for the kernels is about 20°; in other words, the optical characters accord with the view that we are here dealing with, the vertical section of a hornblende crystal which has been largely changed to serpentine.

The only other conspicious mineral in microscopic sections is the one already referred to as forming such a striking macroscopic feature in the rock. Transverse sections of this mineral are lath-shaped and give straight extinction.

In order to determine more precisely the nature of this mineral

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(1 KALKOWSHY describes somewhat similiar relations between amphibolite and serpentine in the Eulengebirge (Die Gneiss-formation des Eulengebirges. 1878. p. 43). In this case the serpentine shows "maschenstructur" and has been formed therefore by the alteration of an olivine-rock. Olivine occurs as an accessary constituent of the amphibolite; so that the transition from amphibolite to serpentine may correspond to an original transition from amphibolite to olivine-rock.

Weigand treated the powder of the rock with weak hydrochloric acid for several days. 3·678 grammes gave ·2599 of a residue which consisted almost entirely of the mineral.

	I.	II.	III.	IV.
SiO_2 ...	37·706	31·098	36·944	46·407
Al_2O_3 ...	0·201	12·701	1·353	6·727
Fe_2O_3 ...	10·428	8·847	6·868	4·649
FeO ...	—	—	3·956	2·107
CaO ...	1·677	5·470	1·393	10·642
MgO ...	36·602	26·714	36·022	26·252
H_2O ...	13·386 (diff.)	15·170 (diff.)	13·089	3·584
	100·000	100·00	99·625	100·368

I. Soluble portion of Rauenthal serpentine.
II. Insoluble ditto
III. Bulk analysis of ditto
IV. Bulk analysis of adjacent amphibolite containing a little serpentine.

The analysis of the soluble portion corresponds to a serpentine containing iron-oxide. That of the insoluble portion shows that the silvery talc-like mineral is a chlorite. The rock analysed is a mixture of serpentine, chlorite and iron-oxides. The bulk-analysis of the adjacent amphibolite shows that it is mainly composed of hornblende rich in magnesia.

The author concludes that the Rauenthal serpentine has been formed by the alteration of a hornblende rock, and that the change has been accompanied by the removal of lime and the developement of a chlorite in which the original alumina of the hornblende is retained.

Passing over several papers[1] in which the views of authors previously quoted are confirmed and extended, we now come to an important communication by Dr. Hussak[2] "Über einige Alpine Serpentine." The rocks investigated by this author belong in part to the Windisch Matrey type, first described by Drasche, and in part to normal olivine-serpentines. The former only need be referred to here.

In the neighbourhood of Sterzing, on the Brenner route to Italy, several isolated exposures of massive and schistose serpentine occur along an east and west line; that is along the strike of the schist with which the serpentine is associated. At the Sattelspitz the relations between the serpentine and the schists (calcareous phyllites) are well exposed. Lenticular masses of serpentine, talc and magnesite occur in serpentinous schists which, in turn, are conformably interbanded with the calcareous phyllites. Lenticles of massive serpentine, also in association with talc and magnesite, occur in

(1) A. Lagorio. Mikroskopische analyse ostbaltischen Gebirgsarten. Dorpat. 1876. p. 43.
E. Kalkowsky. Die Gneissformation des Eulengebirges. Leipzig. 1878. p. 43.
F. Becke. Gesteine aus Greichenland. T.M.M., 1878, p. 459.
(2) T.M.M. Neue Folge. Vol. V., p. 61.

green and blue schistose serpentines at Sprechenstein, near Sterzing. Both the massive and schistose varieties from the last mentioned locality have been carefully investigated by Hussak.

The green schistose serpentine from Sprechenstein is principally composed of scales of a light green mineral with a perfect cleavage of the mica type. Sections at right angles to this perfect cleavage are lath-shaped. They give straight extinction and are distinctly pleochroic; leek-green when the short axis of the nicol is parallel to the cleavage cracks, colourless when the short axis is at right angles to these cracks. The double-refraction of this mineral is slight. Cleavage flakes show in convergent light the optic picture of a biaxial crystal with small axial angle. The double refraction is negative, and the negative bisectrix agrees with the vertical axis. The dispersion is well marked, $\rho > \nu$.

The mineral was isolated by means of the solution of bi-iodide of mercury and potassium, and gave the following analysis:—

		I.		II.
SiO_2	... ...	41·14	... ...	41·58
Fe_2O_3	... ...	3·01	... ...	7·22
Al_2O_3	... ...	3.82	... ...	2·60
CaO	... ...	0·40	... ...	—
MgO	... ...	39·16	... ...	36·80
H_2O	... ...	11.85	... ...	12·67
		99·38		100·87

I. Antigorite from serpentine of Sprechenstein.
II. Do. from Antigora, Piedmont.

It thus appears that this mineral agrees in chemical and optical characters with the antigorite described by Des Cloiseaux. The difference in the amount of iron may be explained by the fact that the mineral from Sprechenstein was entirely free from magnetite.

Lying between the antigorite scales were grains of magnetite and colourless granules of a mineral which gave strong refraction and double-refraction. The larger of these colourless granules showed sometimes two parallel sets of cleavage cracks meeting at 90°, and sometimes only one set of parallel cracks. In the latter case the maximum extinction, referred to the cleavage cracks, was 42° Sections with one set of parallel cleavage cracks and straight extinction (sections parallel to the ortho-pinacoid (100) of an augite-prism) showed an optic axis in convergent light. These characters show that the mineral in question is an augite, poor in iron (Salite).

A brown augite with a perfect cleavage parallel to (100) also occurs sparingly in the rock. This is referred to diallage by the author. Vividly polarising grains of talc are often associated with this diallage. The other minerals of the rock are a green chlorite and staurolite. The latter mineral occurs as small round grains and, more rarely, as columnar crystals. It is yellow in colour and shows a marked pleochroism; γ, dark honey yellow; β and α, pale yellow.

The compact serpentines stand in the closest relation to the schistose variety already described. They consist mainly of antigorite scales; and very commonly these scales are seen to be arranged in two sets of parallel planes meeting at an angle of about 90°, thus producing a netting-like (gestrickte) structure. This netting-like arrangement comes out strongly between crossed nicols. The centres of the meshes are sometimes occupied by salite-grains, many of which give simultaneous extinction. In short the salite-grains are related to the antigorite-serpentine exactly as the olivine-grains to normal serpentine, and the hornblende-grains to the serpentine with lattice-structure. Diallage and staurolite were not observed in the massive serpentine; and chlorite and talc were less common than in the schistose rock.

The following bulk-analyses show the compositions of the schistose (I); and massive serpentines (II), from Sprechenstein.

	I.	II.
SiO_2	40·55	40·90
Fe_2O_3	10·40	7·68
Al_2O_3	2·70	2·08
CaO	4·40	0·30
MgO	33·59	37·45
H_2O	9·32	12·15
	100·96	100·56

There was less unaltered salite in the massive than in the schistose rock. Hence the difference in the amount of lime.

The author concludes that the mother rock of the serpentine was an augite rock belonging to the crystalline schists.[1]

It is unnecessary to follow the author in his description of other serpentines occurring along the same line of strike to the east in the Zillerthal and the district of the Hohe Tauern. The rock from Windisch Matrey in the latter district originally described by Drasche (see ante p. ,) is shown to be a normal antigorite serpentine. Some of the other rocks investigated by that author are proved to be olivine-serpentines; but most of them are augite-(antigorite-) serpentines.

The only other paper to which reference will be made in this historical sketch is by Schulze, on the serpentines of Erbendorf, in Bavaria. These rocks are associated with hornblende-schists, gneisses, talc- and chlorite-schists and have been regarded by Gümbel as due to the alteration of amphibolites. The paper is extremely rich in petrographical details, but as no new type of serpentine is described it will be sufficient to give the conclusions of the author.

(1) The description of the stratigraphical relations and petrographical characters of these serpentines strongly suggests that the district in question has been profoundly affected by regional metamorphism. The lenticular arrangement of the massive serpentines (augen- or flaser-structur on a large scale), the schistose character of the serpentine in certain places, the interbanding with calcareous phyllites, are all features which can be readidy explained by regional metamorphism, and which tend to negative the view that we are here dealing with a stratigraphical sequence.

(1) The true serpentines of the district of Erbendorf are due to the alteration of a rock composed of olivine and an aluminous grammatite: which rock does not appear to have been connected by transitions with the crystalline schists.

(2) Bronzite, in certain places, enters into the composition of the serpentine.

(3) The alumina of the grammatite has given rise to the formation of chlorite.

(4) Grammatite occurs also as a secondary product.[1]

(5) In addition to the true serpentines there occur also others belonging to DRASCHE'S group of "serpentinähnliche Gesteine."

(6) These latter rocks pass over into true serpentines (*i.e.* into rocks yielding a serpentine-analysis,) with a scaly structure.

(7) Both varieties of the serpentine from Erbendorf contain a magnetic iron ore which gives a strong chromium reaction in the borax-bead.

It will be understood that in the preceding historical sketch we have referred only to some of those papers which have exercised a marked influence on the development of the opinions now generally held on the serpentine question. Many papers of great local importance have of necessity been passed over. Considerable prominence has been given to the later papers because the recent improvements in petrographical methods have enabled students to solve many problems that the old masters of our science could not attack with any reasonable prospect of success. We may sum up the more important points which appear to be definitely established, by saying that three definite types of structure of genetic importance are now recognised.

(1) Serpentine with "maschen-structur" or olivine-serpentine.

(2) Serpentine with lattice-structure (Gitter- or Fenster-structur) or hornblende-serpentine.

(3) Serpentine with netting-like structure (gestrickte-structur) or augite- (antigorite-) serpentine.

BRITISH SERPENTINES.

It is to Professor BONNEY that we are principally indebted for our knowledge of the true character of many British serpentines. He has investigated the field relations and microscopic characters of the rocks of this class as they

(1) This agrees with BECKE'S observation on "Pilite." WEIGAND'S researches prove that serpentine may be produced by the alteration of grammatite (colourless hornblende); BECKE'S researches show that a similar mineral may arise as a secondary product in connection with the formation of serpentine.

are developed in the Lizard District of Cornwall,[1] in Anglesea,[2] in Ayrshire[3] and Aberdeenshire.[4]

With regard to field relations, he believes that in the Lizard and in Ayrshire the appearances can only be explained on the assumption that the mother-rock of the serpentine was intrusive. In the other cases the field relations are not so clear; but as nothing was seen to negative the view that the original rock was igneous and as the serpentines from all the above localities resemble each other in their petrographical characters, he concludes that they are all of similar origin.

Typical serpentine is a compact rock with a splintery or, in some cases, conchoidal fracture. It is readily scratched with a knife (hardness about 3 or 4), and possesses a specific gravity of 2·5 or 2·6. It varies extremely in colour and, as it takes a good polish, has been extensively used for the purpose of making small ornaments. The brittleness of the rock and the difficulty of obtaining large blocks free from joints prevents its general use for the larger ornamental purposes.

The prevailing tints of the ornamental serpentines are yellowish green, pale green, deep green, brownish red and blood red. Irregular blotches or anastomosing veins of one colour often occur in a groundmass of another colour. Thus, some of the most beautiful varieties are due to blotches and veins of a blood red variety of serpentine in an olive-green groundmass. Veins of chrysotile and white steatite and porphyritic crystals of bastite frequently occur. In addition to the above varieties, all of which are more or less used for ornamental purposes, we find largely developed in the Lizard peninsula and occurring also in Ayrshire, a black variety with conspicuous glistening crystals of bastite. In the former locality also occur dark banded serpentines with minute glistening crystals of a pale coloured hornblende (grammatite). This latter variety also occasionally contains large porphyritic crystals of bastite.

As a rule serpentine is dull and opaque; sometimes, however, it is translucent. Translucent varieties suitable for the more delicate ornamental purposes are termed noble serpentine. The only British locality in which noble serpentine has been recorded, so far as the present writer is aware, is Hillswickness in Shetland.[5]

White steatite, a substance which differs from serpentine in containing more silica and less water or, in more precise chemical language, in being a bisilicate instead of a uni-silicate, often occurs in association with serpentine. Sometimes, as already mentioned, it forms veins in the serpentine, and at other times angular fragments of normal serpentine lie embedded in a white steatitic groundmass.

To describe all the macroscopic varieties of serpentine would be an endless and unprofitable task. They are doubtless due partly to variations

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(1) Q.J.G.S., Vol. XXXIII., (1877), p. 881.
(2) Q.J.G.S., Vol. XXXVII., (1881), p. 40.
(3) Q.J.G.S., Vol. XXXIV., (1878), p. 769.
(4) G.M., Decade III., Vol. II., (1885), p. 439.
(5) Dr. Heddle. Trans. Roy. Soc., Edin., Vol. XXVIII., p. 239.

in the composition of the original rock and partly to secondary causes. The serpentinisation has been produced by percolating solutions which, in some cases, certainly oxidised the iron and thus gave rise to the red varieties, and in other cases exercised a reducing effect. By means of these solutions the original minerals were not only decomposed *in situ*, but a considerable amount of migration of certain chemical constituents was rendered possible as is shown by the formation of veins of chrysotile, steatite, calcite and chalcedony. The manner in which these solutions penetrated the rock-mass was doubtless determined by joints produced partly in connection with the original consolidation of the peridotite, and partly in all probability by the earth-movements that have affected the districts since the formation of the original rock. Again, in certain localities, as for example near Nare Head, on the east side of Gerran Bay, Cornwall, the serpentine has been converted into a soft soapy schist by earth-movements acting after the formation of the serpentine. It appears clear to the present writer that most of the districts in which serpentine is known to occur in Britain have been profoundly affected by regional metamorphism; and if so it becomes a matter of great importance to determine the relation between the times of intrusion, serpentinisation and regional metamorphism.

Minerals of the Serpentine Rocks.

Serpentine.—The most important is of course serpentine itself. In thin sections this appears either yellow, green or colourless. It is frequently either stained red by ferric oxide or rendered more or less opaque by the black oxides of iron. As already stated the distribution of the iron oxides marks out the original structure of the olivine, when the serpentine has been derived from that mineral. When examined under crossed nicols serpentine splits up, as a rule, into double-refracting bands and isotropic portions. The double-refracting bands intersect each other, and thus produce a network which corresponds with the original structure of the mineral from which the serpentine has been produced. The isotropic portions lie in the centres of the meshes. The existence of double-refracting and isotropic portions of one and the same substance is thus explained by Rosenbusch. The minute structure of serpentine is fibrous. The individual fibres have definite optical characters which can be determined in the case of those aggregates in which the corresponding crystallographic planes of the fibres lie parallel to each other; as for example in chrysotile. They are biaxial with a large optic axial angle and a negative bisectrix at right angles to their length. Where the fibres are arranged with more or less parallelism the serpentine exhibits double refraction; where, on the other hand, the serpentine is isotropic the fibres are confusedly intermingled and compensation takes place. When the serpentinisation has proceeded from any plane the fibres tend to arrange themselves at right angles to this plane.

Bastite, the serpentinous modification of enstatite, possesses a distinct lamellar structure, determined by the pinacoidal cleavage of the mineral from which it has been derived. In it the parallel arrangement of the individual

fibres is strongly marked, though not absolutely perfect. The long axes of the fibres lie approximately parallel with the vertical axis of the pyroxene. This mineral commonly forms the glistening crystals in many porphyritic serpentines

Next in importance to the serpentine itself are the minerals from which the serpentine has been derived. The most important of these, so far as the British serpentines now under consideration are concerned, are olivine, enstatite and hornblende.

Olivine.—Unaltered olivine is very abundant in many localities in Cornwall, as for example at Coverack Cove, Mullion Cove, Pradanack, Landewednack and Kynance Cove. Every stage of the transition from a rock extremely rich in olivine to one in which all traces of the original mineral have disappeared may be observed. The olivine is almost colourless in thin section.

Enstatite.—Unaltered enstatite is abundant in certain localities. It is colourless in thin section and possesses the strongly-marked cleavage of a pyroxene. Alteration commences at the surface and along the cracks by the formation of a finely fibrous structure, and ends in the formation of a bastite-serpentine in which the fibrous structure is usually more or less preserved.—(See Fig. 2, Plate I.) The large crystals with one strongly marked plane of separation and a brilliant metallic lustre, which give a marked porphyritic character to many serpentines, belong in all cases examined by the author to bastite. Cleavage flakes which may be detached by the aid of a penknife show in convergent polarised light a negative bisectrix.[1]

The following analyses by Dr. HEDDLE appear to have been made from specimens of this mineral :—

	I.	II.
SiO_2	38·186	37·776
Al_2O_3	2·178	2·123
Cr_2O_3	·276	—
Fe_2O_3	·028	5·069
FeO	8·479	2·095
MnO	·513	·076
CaO	2·912	—
MgO	32·418	37·014
K_2O	1·401	tr.
Na_2O	·065	
H_2O	14·03	16·07
	100·486	100·223

(1) Bastite is distinguished from bronzite by this character. In the latter mineral the plane of easy cleavage is parallel to the optic axial plane, and cleavage flakes give, therefore, no definite optic picture. Diallage may be easily distinguished from either of the above minerals by the fact that cleavage flakes show an optic axis somewhat oblique to the axis of the instrument,

I. From serpentine near the Black Dog, Aberdeen. Trans. Roy. Soc. Edin., Vol. XXVIII., p. 500.

II. From serpentine, Balhammie, Ayrshire. Trans. Roy. Soc. Edin, Vol. XXVIII., p. 494.

Augite (Diallage).—A monoclinic pyroxene has been observed by Professor Bonney in some varieties of the Lizard serpentine. It appears, however, to be much less abundant than either olivine or enstatite, and was doubtless entirely absent from large masses of the mother-rock of the serpentine.

Hornblende.—This mineral is of considerable interest, and occurs very abundantly in certain varieties of the Lizard serpentine. The serpentines with hornblende differ, as a rule, in a marked manner from those which do not contain this mineral. They are dark in colour and often exhibit a banding due to variation in the relative proportions of the constituent minerals. The veins and blotches of colour which give such a marked character to the serpentines without hornblende, are usually absent from the rocks which contain this mineral in abundance. On fractured surfaces the hornblende may be recognised by the small bright cleavage faces. As a rule the crystals are minute, but sometimes they measure an eighth or even a quarter of an inch in length.

In thin section the hornblende is usually seen to be colourless or a very pale green. Sometimes indications of a brown tint may be observed. It occurs in irregular grains, elongated in the direction of the vertical axis. The cleavage cracks are well marked and highly characteristic. The maximum extinction in the prismatic zone is about 20°. This hornblende appears to be similar to that of certain Norwegian peridotites, to that of the Rauenthal serpentine, described by Weigand, and to that of certain serpentines from Erbendorf in Bavaria described by Schultze. [1] It belongs to the grammatite variety and passes over into serpentine in the manner described by Weigand and Schultze. (See *ante* p. 111.)

In addition to the hornblende above referred to, which appears to have formed a constituent of the mother-rock of the serpentine, we find also in certain veins a colourless variety which takes the form of long prisms (tremolite), often grouped in a more or less radial manner. This variety must certainly be of secondary origin.

Felspar.—This mineral is very rare in the serpentines. Professor Bonney records it as occurring at Gue Graze in the Lizard district. It is present also in slides of a variety of serpentine from the Rill Head, near Kynance, lent to the author by Mr. Waller. It occurs in irregular grains which show the characteristic twinning on the albite plan. The angle between the extinction positions of two adjacent lamellæ which gave approximately symmetrical extinctions was 53°; a fact which shows that the species must be allied to bytownite.[2]

(1) Z.D.G.G., Vol. XXXV., p. 433.

(2) The author has recently visited the district and asertained that serpentine containing felspar forms a large portion of the Rill Head. The original rock was, therefore, of the nature of a picrite.

Chromite and Picotite.—These minerals which are of such constant occurrence in olivine rocks have been recorded by Professor BONNEY as occurring in the Lizard serpentines at Lower Pradanack quarry, Goonhilly Downs, Cadgwith and the Balk. In a variety from Coverack (Cornwall) they occur in the form of irregular masses of a deep rich brown colour when viewed in very thin sections. They have been recorded also by Professor BONNEY from the serpentines of Ayrshire and Aberdeenshire.

Secondary Minerals.—In addition to the serpentine and tremolite already referred to we find calcite, steatite, chrysotile and chalcedony occurring as veins in the rock. The examination of thin slices of the Lizard serpentines also shows the frequent presence of a colourless mineral with one strongly-marked cleavage. Sections at right angles to this cleavage are lath-shaped in form and give straight extinction. The polarisation tints are low, and this fact appears to prove that it is not talc, the mineral to which one would, at first sight, naturally refer it. In all cases examined by the author this mineral is so small that cleavage flakes, for more precise optical or chemical determination, cannot be obtained. It may be a colourless chlorite like that of the Rauenthal serpentine, or a mineral allied to the antigorite of the augite-serpentines described by DRASCHE and HUSSAK.[1] Native copper has been worked in serpentine, near Mullion, Cornwall.

Varieties of British Serpentine.

In describing the more important varieties of British serpentine it will be convenient to refer to them as they are developed in the several localities. The most extensive development of serpentine in the British Islands appears to occur in the Lizard peninsula of Cornwall. The rock is represented on the geological map as covering an area of about twenty square miles. It forms a gently undulating plateau which is bounded on the east and west by precipitous and mostly inaccessible cliffs. Few exposures of rock occur over the general surface. The rocks associated with the serpentine are gabbro and hornblende schist, and some difference of opinion still exists as to the precise relations of the different rock-masses. Speaking of the hornblende schist DE LA BECHE says: [2]—"It supports the great mass of the Lizard serpentine with an apparent passage of the one into the other in many places. An apparent passage somewhat embarrassing inasmuch as there is reason to conclude from the grauwacke conglomerate of the Nare Point, in the north part of the Lizard district, that hornblende slates were in existence, forming a surface from which large portions were abraded by the action of water, while the serpentine and diallage rocks of the Lizard were not formed; for rounded pieces of the hornblende slate though rare are found in the conglomerate, while no trace has yet been discovered of serpentine or diallage rock. . . . . Whatever the cause of this apparent passage may have been it is very readily seen at Pradanack Cove, at the coast west of Lizard town, and at several places on the east

(1) See *Ante*, p. 113.

(2) Report on the Geology of Devon and Cornwall. Memoirs of the Geological Survey, Vol. I., 1839, p. 30,

coast between Landewednack and Kennack Cove, more particularly under the Balk, near Landewednack, and at the remarkable cavern and open cavity named the Frying Pan, near Cadgwith. . . . . In contradiction to this apparent passage we find a mass of serpentine amid the hornblende slate, between Dranna Point and Porthalla, on the north of the principal mass of serpentine which has every appearance of having been thrust up among the hornblende slate, twisting and contorting the laminæ adjoining it in directions which we should consider consistent with the passage of the serpentine in a state of igneous fusion through them."

Professor Bonney has studied the relations of the serpentine to the hornblende-schists and arrived at conclusions different from those expressed in the above quotation. Many of the junctions, referred to by De la Beche as indicating a passage from hornblende-schist to serpentine, he regards as conclusive in favour of the view that the mother rock of the serpentine was intrusive. Thus, at Pentreath Beach, west of Lizard Town, the serpentine is held to be intrusive, and fragments of the hornblende schist are mentioned as occurring in it. At George's Cove "tongues of serpentine are thrust into the schist within a foot or two of the junction." Hornblende-schists "with intrusive tongues of serpentine occur near Perranvose on the east coast near Landewednack." At the Balk, also near Landewednack, saussuritic and actinolitic gabbro occur in association with the serpentine; and the latter rock is seen, according to Professor Bonney, to be intrusive, in the schist and in the serpentine. At the Devil's Frying Pan, near Cadgwith, "the relations of the serpentine with the schist, as seen by descending into this hollow, leave no doubt that the former rock is intrusive." At Coverack Cove the serpentine is seen in relation with troctolite (older gabbro of Professor Bonney's first paper) and gabbro. The latter is a part of the great mass of Crousa Down which forms the coast line between Coverack Cove and Manacle Point, a distance of two miles.

In addition to the rocks above mentioned dykes of granite occur on the west coast, and dykes of "greenstone" (epidiorite) on the east.

If we examine the descriptions given by Professor Bonney of the field relations and microscopic characters of the gabbros, and still more if we examine the rocks themselves in the light of the researches of Lossen in the Hartz and Lehmann in Saxony, it is impossible to avoid the conclusion that the Lizard peninsula has been profoundly affected, and probably at more than one period, by regional metamorphism. It must be remembered that Devon and Cornwall form a part of the great Hercynian chain of northern Europe; that they contain the same rocks and have been affected at the same periods by the same earth-movements. The effects of regional metamorphism on the basic igneous rocks of Devon and Cornwall, which were formed before the great earth-movements took place, will be described later on; at present the subject is only referred to because it serves to suggest that the discrepancies, between different observers, as to the field relations of the serpentine may possibly arise from complications due to the later earth-movements.

Many varieties of serpentine depending on variations in the mineralogical

composition of the mother-rock, may be recognised in the Lizard district. These varieties can, however, in many cases only be distinguished from each other by the examination of thin slices under the microscope. Some of the serpentines appear to have been derived from an olivine rock (dunite), others from an olivine-enstatite rock (saxonite) and others from an olivine-enstatite-augite rock (lherzolite). In the olivine-enstatite serpentines the latter mineral is more frequently represented by porphyritic crystals of bastite which yield bright glistening cleavage surfaces. The black serpentine so largely developed on the coast at various points to the north of Cadgwith, is a good illustration of this variety. Near Mullion Cove, Kynance Cove and at some other localities, rocks largely composed of olivine and hornblende occur, and in some of these the latter mineral is quite as abundant, if not more abundant than the former. Both minerals pass over into serpentine. Another point of considerable interest in relation to these rocks is the fact that they frequently show a marked banding due to a variation in the relative proportions of the different constituents. In this respect, as also in respect of their original mineralogical composition, they bear a close relation to the peridotites of the Almeklovdal type described by Messrs. Reusch & Brögger. The latter rocks, are, however, perfectly fresh, whereas the Lizard rocks are all more or less serpentinised. Porphyritic crystals of bastite may occasionally be observed in the olivine-hornblende serpentines, but as a rule they are absent. The occurrence of bastite is of importance, because it serves to link the serpentines containing hornblende with those from which this mineral is absent. Picotite also occurs in the olivine-hornblende serpentines.

Speaking of the distribution of the different varieties Professor Bonney says:—"The handsome mottled varieties, with conspicuous crystals of bronzite [bastite] occur chiefly in the southern and south-eastern regions, along the coast from the Balk, near Landewednack, to Coverack Cove, and for a considerable distance inland, at any rate to the neighbourhood of Ruan Major, the fine black variety with glittering bronzite [bastite] crystals being found on the coast south of Caerleon Cove; they occur also on the western coast, some distance to the north of Kynance Cove (near the Horse). South of that, and at the Rill, as well as to the north at Gue Graze, George Cove, and near Mullion Cove, compact dull coloured varieties are commoner, and these are seen by the Helston Road on the northern part of the mass. In close association with these is the dull coloured variety, containing small glittering crystals, which appear to be mainly a pyroxenic or hornblendic mineral [grammatite], found especially about Lower Pradanack and in Mullion Cove, but occurring locally also in one or two localities on the eastern coast about Dolor Hugo and the Frying Pan. A streaky structure is not seldom visible in these dull coloured varieties, and this is especially conspicuous in the outlying mass at Porthalla, and in the more eastern part of the northern edge of the great mass on Goonhilly Downs (though here the rock is more highly coloured)."

It appears then to be established beyond all doubt that the Lizard mass of ultra-basic rock, from which the serpentine has been produced, varied extremely in mineralogical composition: dunites, saxonites, lherzolites, and probably picrites were represented within it, and also olivine-hornblende rocks. Taking it as a whole, and leaving out of account the banded olivine-hornblende rocks, it must have been very similar in character and composition to the complex mass of Tertiary peridotites recently described by Professor JUDD [1] as forming so large a portion of the Island of Rum. The Lizard mass has, however, been both serpentinised and modified by regional metamorphism, whereas, the core of the Tertiary volcano has been simply exposed by denudation. To the north of the main mass of Lizard serpentine are two small exposures of the same rock near Porthalla. Here it also occurs in association with hornblende-schist. Speaking of the exposure nearest Porthalla, Professor BONNEY says, [2] "The serpentine varies from a dull purplish green to a greenish grey—the latter colour denoting the more weathered specimens. Sometimes it is a homogeneous dark rock, at other times it exhibits a very marked streaky aspect, reminding one of the fluidal structure of rhyolites. I consider the rock to be an altered peridotite, but to have been originally rather finely crystalline. No crystals of enstatite, hornblende, or augite are now recognisable." Professor BONNEY regards the rock as intrusive in the hornblende-schist. Mr. Collins gives a different interpretation. He considers that the two rocks are interbanded and connected with each other by transitional forms.

A small patch of serpentine occurs also near Nare Point, on the east of Gerran's Bay. The relations of this mass are not well exposed. The neighbouring rocks are gabbro, quartzite and other altered sediments. The serpentine is in part a true massive serpentine with chrysotile veins, and in part a soft serpentine-schist. Flat lenticles of the latter rock are abundantly strewn over the lower slopes of a field at the back of the little bay of Gilberick. This exposure of serpentine and gabbro is of some interest, because it is known that the quartzite and its associated beds, including the limestone of Gorran Haven, in which Mr. PEACH discovered fossils, is of Ordovician age. The relation of the igneous to the sedimentary beds is not clear, but in the absence of pebbles of diallage and serpentine from the Ordovician conglomerates of the neighbourhood, it seems probable that the former were intrusive in the latter. If so it is evident from the serpentine-schist that powerful earth movements have affected the district since the date of intrusion.

The following analyses represent the compositions of different varieties of Lizard serpentine.

(1) Q.J.G.S. Vol. XLI., 1885, p. 354.
(2) Q.J.G.S. Vol. XXXIX., 1883, p. 21.

	I.	II.	III.	IV.	V.
SiO_2	38·50	38·60	37·15	39·50	38·86
Al_2O_3	1·02	·10	5·60	5·08	2·95
Cr_2O_3	—	—	—	—	·08
Fe_2O_3	4·66	11·55	1·10	8·12	1·86
FeO	3·31		8·80		5·04
NiO	·59	—	—	—	·28
CaO	1·97	tr.	0·10	tr.	tr.
MgO	36·40	33·62	32·80	34·65	34·61
FeS_2	·41	—	—	—	—
H_2O	12·35	12·82	14·16	12·55	15·52
Alkalies and loss	—	3·31	0·29	0·10	1·1
Insol. in HCl	1·37	—	—	—	—
	100·58	100·00	100·00	100·00	100·30
Sp. Gr.	2·587	2·65	2·56	2·545	

I. Black serpentine near Cadgwith containing porphyritic crystals of bastite. The crystals lose 9 p.c. on ignition. This agrees with the optical determination, and proves them to be bastite. Analysis by Mr. Huddleston (Q.J.G.S., Vol. XXXIII., 1877, p. 925).

II. Greyish-green granular serpentine. Porthalla. Analysis by Mr. Collins (Q.J.G.S., Vol. XL., 1884, p. 467).

III. Dark oil-green serpentine. Porthalla.

IV. Reddish-brown granular serpentine. Porthalla. Analyses II., III. and IV. are all by Mr. Collins, and quoted from the same paper. The SiO_2 includes also the insoluble residue.

VI. Ornamental serpentine from the Lizard. Dark groundmass blotched with red. The rock contained also traces of MnO. 2·06 of the water was lost in the water-bath. Analysis of J. A. Phillips. Phil. Mag., vol. XLI., 1871, p. 101.

At Clicker Tor, near the Menheniot Railway Station, and about three miles south-east of Liskeard, is another small patch coloured as serpentine upon the geological map. The rock has been investigated both by Mr. Phillips [1] and Mr. Allport.[2] It was well exposed during the construction of the Cornish Railway, and is, indeed, still quarried close to the Station at Menheniot. At the time of Mr. Phillips's visit it exhibited a schistose structure, and did not appear to be sharply separated from the surrounding killas. These facts seem to show that here, as at Nare Head, the serpentinous rock has been affected by earth-movements. When Mr. Allport examined the rock its relations to the surrounding sediments appear to have been better exposed, and he describes it as an instrusive mass. Speaking of the microscopic structure of the rock (See plate II. fig. 2), Mr. Allport says:—" A thin slice

(1) Philosophical Magazine. Vol. XLI., p. 100.

(2) Q.J.G.S. Vol. XXXII., 1876, p. 422.

exhibits a variegated mass of pale green serpentine and a nearly colourless substance intimately blended together (see figure): imbedded in this matrix there are numerous pseudomorphs after olivine, and irregular plates of unaltered augite, together with minute grains of magnetite, scattered here and there through the mass. The pseudomorphs after olivine are of two kinds, consisting either of serpentine or the white colourless substance just mentioned; both are highly characteristic; the crystalline forms are perfectly preserved, and they are traversed by veins representing the original cracks so generally found in this mineral. Although the groundmass of the rock exhibits a confused appearance both in ordinary and polarized light, we are fortunately not left in doubt as to the nature of at least one of the original constituents. The augite frequently encloses highly characteristic pseudomorphs after felspar; some are completely enclosed, while others are only partially embedded in it.

In many cases the unaltered augite has preserved in the most perfect manner the sharp edges and angles of the felspar prisms; and whenever the latter project from the augite, it may be readily seen that both the enclosed and outlying portions have been converted into precisely the same serpentinous substance as that forming the groundmass. It should also be noted that, in the case of partially enclosed prisms, only those sides or ends which have impressed their shape on the augite exhibit a crystalline form, the outstanding portion being quite undistinguishable from the surrounding mass." Mr. Allport regards the rock as furnishing an illustration of the partial serpentinisation of an olivine-dolerite. The extraordinary abundance of the olivine, as evidenced by the numerous pseudomorphs, and the comparatively small amount of felspar which can have been present, are sufficient to place the original rock in the picrite group. Professor Rosenbusch refers to a picrite from Liskeard in his Mikroskopische Physiographie der massigen Gesteine (1st Edition p. 530), and there can be no doubt from his description that he is speaking of the rock now under consideration. He mentions the occurrence of minute colourless microlites in the sepentine after olivine, and doubtfully refers them to a grammatite-like amphibole. In some of the slides examined by the present writer, cross sections of these microlites give the outline of a hornblende prism, and leave no doubt as to the correctness of Professor Rosenbusch's suggestion. Here then we have another illustration of the formation of secondary hornblende in connection with the serpentinising process.

One of the most interesting points about this rock is the evidence it affords of the alteration of felspar into a substance which blends in the most intimate manner with the serpentine derived from olivine. We have no direct evidence of the nature of this, but it is probably the substance which has frequently been termed pseudophite; that is a substance which retains the original alumina of the felspar in combination with magnesia and water; the lime and alkalies having been removed. It is instructive to notice that in this rock the felspar and olivine have both been attacked and completely destroyed, whereas the augite is frequently preserved.

Anglesea.—Several patches of serpentine are represented on the one-inch geological map of Anglesea. These patches are very briefly referred to in

the Survey Memoir on the district,[1] but they have received more extended notice by Professor Bonney[2] from whose paper the following account is taken. The ordinary rock of the district in which the serpentine occurs is "a dull bluish or greenish schist, composed chiefly of minutely crystallised micaceous or chloritic minerals with some quartz." This rock often exhibits the most remarkable crumplings. Gabbro is also found in intimate relation with the serpentine, and the colour representing the latter rock, on the map, is often made to include the former. The gabbro is often foliated as at the Lizard, and on the bank of an inlet near Tyddyn Gob, "is a rather schistose rock which in the lower part resembles a foliated gabbro, in the upper a schist." At Ty Ucha the serpentine shows the characteristic net-like structure and "probably results from the alteration of an olivine-rock—a kind of dunite." Near Cruglas Farm serpentine veined with calcite occurs, and in some places the rock is a kind of ophicalcite. At Ceryg Moelion a crushed and slickensided serpentine occurs in association with ophicalcite. At Ty Newydd altered enstatite is found in addition to the serpentine derived from olivine, and the rock yielded to Mr. Houghton the following analysis :—

SiO_2	38·62
Al_2O_3	4·15
Fe_2O_3	5·21
FeO	4·34
MnO	tr.
CaO	tr.
MgO	33·83
Na_2O (K_2O)	·70
H_2O	12·52
	99·37

It appears, therefore, that the Anglesea serpentines in many respects bear a close relation to those of Cornwall. They give distinct evidence in places of having been derived from olivine rocks, and they occur in intimate relation with gabbro which is often foliated and sometimes appears to pass over into a true schist. The crumpling in the surrounded rocks, the foliation in the gabbro and the crushed and slickensided aspect of the serpentine in certain places all bear testimony to the fact that the rocks of the district have been profoundly modified by regional metamorphism. The precise relations of the serpentine to the surrounding schists are not yet explained.

Carrick, Ayrshire.—The rocks of this district have been described by Dr. J. Geikie[3] and Professor Bonney.[4] The following description is

(1) Memoirs of the Geol. Survey, Vol. III.

(2) Q.J.G.S., Vol. XXXVII., 1881, p. 40.

(3) Q.J.G.S., Vol. XXII., 1866, p. 513.

(4) Q.J.G.S., Vol. XXXIV., 1878, p. 771.

taken from Professor BONNEY's paper. At Balhammie Hill, near Colmonell, a serpentine containing brilliant crystals of bronzite (bastite ?) in a black groundmass occurs. The rock is identical in appearance with the black serpentine near Cadgwith, Cornwall, and appears to have been originally composed of olivine and enstatite. The conspicuous porphyritic crystals have been analysed by Dr. HEDDLE (see *ante* p. 118), and the black groundmass, deprived of the crystals, by Mr. HOUGHTON. Mr. HOUGHTON's analysis is as follows :—

SiO_2	38·29
Al_2O_3	3·95
Fe_2O_3	2·53
FeO	4·04
CaO	0·57
MgO	35·55
MnO	tr.
NiO	0·15
FeS_2	tr.
H_2O	14·08
	99·16

Along the coast by Lendalfoot serpentine is seen in association with the so-called "dioritic" rocks. These latter, in the few cases investigated by Professor BONNEY, contain augite and not hornblende. They are in part massive and in part schistose. They represent, as it were, the hornblende schists of Cornwall, and are in all probability massive igneous rocks which have been more or less affected by regional metamorphism. The junctions between the serpentine and these latter rocks are sharp and irregular, and "tongues of the serpentine penetrate the diorite." The serpentine about Lendalfoot has a "rather conchoidal fracture with a very compact dark olive green groundmass, containing rather minute and not very lustrous bronzitic crystals and thin veins of chrysotile." Picotite is present.

A dull red serpentine with bastite occurs to the south of Carleton foot. A greenish serpentine mottled with white steatite occurs near the stone marking five miles from Ballantrae. North of Lendalfoot saussuritic gabbro and massive diallage rock occur in association with serpentine. The gabbro, like that of Cornwall, contains saussurite, a little unaltered plagioclase, diallage, uralite and actinolite.

Other Scotch Serpentine Localities.—One of the best known of these is Portsoy in Banffshire. Here, as elsewhere, the rock occurs in relation with gabbro and plagioclase-hornblende rocks (diorite). Dr. HEDDLE [1] to whom we are indebted for a description of the mineralogical

(1) Trans. Royal Soc. Edinburgh, Vol. XXVIII., 1879, p. 514.

characters of the rocks of the locality, states that on the west shore of the Bay of Durn serpentine alternates at least five times with an equal number of beds of diorite. Two masses of serpentine occur to the west of Portsoy. Portions of the larger of these form, when polished, a highly ornamental stone, there being a mixture of blotches of a bright red colour throughout a groundmass of green and white. The smaller, or more easterly of the two masses, resembles an intrusive dyke, and terminates in the sea. Typical gabbro occurs according to Dr. HEDDLE in a small sea-stack, whereas the adjoining portion of the main mass shows a transition from gabbro to serpentine. Dr. HEDDLE is of opinion that a portion, if not the whole, of the serpentine has been formed by the alteration of an augite-plagioclase rock. In view of the researches of TSCHERMAK, BONNEY and others, this seems highly improbable, and the present writer possesses a slide of Portsoy serpentine, which not only shows the typical "maschen-structur," but contains also original olivine in the centres of the meshes. In the face of this direct evidence of the occurrence of olivine, it is to say the least, extremely doubtful whether any portion of the mass was originally free from this mineral.

Near Kirriemuir, in Forfarshire, occurs the remarkable dyke described by SIR CHARLES LYELL [1] and Professor JUDD.[2] It varies in width from 100 to 300 yards, and encloses masses of the rocks traversed by it. These rocks belong to the Old Red Sandstone, and they are markedly affected by the dyke. Professor JUDD says:—"At its sides the rock is a mass of serpentine traversed by numerous veins of chrysotile, and exhibiting no evidence of the minerals from which the rock was originally formed. But towards the centre crystals of "Schiller-spar" make their appearance, and the serpentine gradually passes into a hard crystalline mass. Studied by the aid of the microscope this central and least weathered part of the dyke is seen to be made of serpentine, clearly pseudomorphous after olivine, and containing large crystals of a ferriferous enstatite in a more or less advanced stage of alteration into bastite and serpentine. In some portions of the mass of the dyke the ferriferous enstatite prevails almost to the exclusion of the olivine, and we have a rock strikingly resembling the bronzite-rock of the Kupferberg, near Bayreuth, and of St. Stephan in Upper Styria. Among the dykes which intersect the great serpentine mass, I found one to consist of a coarse dolerite or augite-gabbro, while another is a very beautiful example of a hypersthene (ferriferous enstatite) dolerite."

The occurrence of serpentine at the localities north of Aberdeen—one in the parish of Belhelvie, and the other on the shore close to the rock known as the Black Dog—has been noted by Dr. HEDDLE,[3] and the rocks have been examined and described microscopically by Professor BONNEY.[4] They consist of serpentine derived from olivine, with the characteristic maschen-structure,

(1) Edin. Jour., see vol. III. (1825) p. 112.
(2) Q.J.G.S. Vol. XLI., 1885, p. 399.
(3) Min. Mag. Vol. V., p. 1.
(4) G.M. Decade III. Vol. II., 1885, page 439.

and bastite, containing enclosures of serpentinized olivine. They resemble very closely, both macroscopically and microscopically, the serpentine with bastite from Baste (Harz), Kupferberg (Bavaria), and Santa Catarina (Elba). The rock with which the serpentine is immediately associated at Bellhelvie is a plagioclase-olivine rock (troctolite), in which the relative proportions of the two principal constituents exhibit a considerable amount of variability; in some varieties the felspar, in others the olivine is the dominant mineral. Here, as elsewhere, we have evidence of the variability in composition, which is such a constant feature in rock masses of ultra-basic composition. The mother-rock of the serpentine examined by Professor BONNEY was a saxonite (olivine-enstatite rock). The bastite of the serpentine mass near the Black Dog was isolated and analysed by Dr. HEDDLE. (See *ante* p. 118.)

Serpentine occurs at other localities in Aberdeenshire, as for example at Barra Hill, near Old Meldrum, [1] and near the railway station, Rothiemay. It is found also at Polmally in Glen Urquhart, at Killin in Perthshire, at Colafirth Voe in the mainland of Shetland, and in the outlying islands of Unst and Fetlar, where it occurs in association with diorite and gabbro, as at Portsoy. In the absence, however, of detailed petrographical descriptions of the rocks of these localities it is impossible to give precise details in the present work.

The serpentines of Connemara, and the Highlands and Western Isles of Scotland, which occur in association with crystalline limestones, will be referred to in connection with the latter rocks.

Messrs. KING and ROWNEY [2] mention the occurrence of a serpentine at South Cannaver Island, Lough Corrib, which appears to be formed by the alteration of radiating masses of actinolite or tremolite. They state that their attention was called to this case by Mr. KINAHAN, who has referred to it in the description of Sheet 95 of the Geological Survey of Ireland.

At Duporth, two miles east of St. Austel, occurs a rock of somewhat remarkable composition which may be referred to in this connection, though it is certainly not a true serpentine. It is remarkably soft and may be readily cut with a knife. It is grey, or greenish grey in colour, on a rough surface, but is capable of taking a good polish, and then one sees pale green spots on a darker groundmass. These spots sometimes show definite crystalline boundaries which suggest that they are pseudomorphs after olivine. Two analyses have been made of somewhat different varieties of this rock; one by Mr. PHILLIPS,[3] (I.), the other by Mr. COLLINS,[4] (II). The analysis of a picrite from Gümbelberg is quoted for comparison (III.)

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(1) Dr. HEDDLE, Trans. Roy. Soc., Edin., vol. XXVIII., p. 554.

(2) An Old Chapter of the Geological Record, 1881, p. 39.

(3) On the so-called Greenstones of Central and Eastern Cornwall. Q.J.G.S., Vol. XXXIV., 1878, p. 474.

(4) On the Serpentine of Duporth, in St. Austel's Bay, Cornwall. British Association Report for 1877.

	I.	II.	III.
SiO_2	35·74	37·09	40·79
TiO_2	—	tr.	—
Al_2O_3	12·23	19·90	10·41
Fe_2O_3	4·68	15·54	3·52
FeO	13·84	2·02	6·39
MnO	0·98	tr.	—
CaO	tr.	tr.	8.48
MgO	22·13	15·90	23·34
K_2O	tr.	tr.	0·71
Na_2O	0·25		1·71
P_2O_5	0·18	·21	—
H_2O	10·01	8·65	4·04
	100·04	99·31	99·39

Mr. Phillips states that the specimen analysed by Mr. Collins was harder and darker than the one he had analysed, and contained fewer of the light coloured pseudomorphs. It will be observed that Mr. Collins' analysis shows less magnesia, a fact which agrees with the view that these pseudomorphs are after olivine. Under the microscope the rock is seen to consist mainly of a confused mass of fibres and scales; some patches of this give vivid aggregate polarisation, whereas the intervening portions are almost isotropic. The only definitely recognisable minerals in the slide examined by the writer are a brown mica and magnetite. It seems probable from the amount of alumina in the rock that we have here a mixture of serpentine and pseudophite, the serpentinous alteration product after felspar. The original rock appears to have been a picrite, as may be seen by comparing the analysis of Mr. Phillips with that of the picrite from Gümbelberg. It is instructive to notice, however, that the alteration of the Duporth picrite has given rise to results the exact opposite of those described by Tschermak. In the picrites of Moravia and Silesia the effect of the alteration has been to remove magnesia and to replace it by lime. Here the lime has been almost entirely carried away, while magnesia has remained or possibly even been introduced into the rock.[1] It is also interesting to notice that the Duporth rock lends no support to the view that a true serpentine may be produced by the alteration of a felspathic rock. The original alumina has not been carried away.

(1) The altered picrite from Söhle yielded SiO_2 42·85, Al_2O_3 10·42, Fe_2O_3 6·27, FeO 6·86, CaO 11·84, MgO 9·01, K_2O 1·61, Na_2O 1·65, H_2O 2·70, CO_2 5·88. Total 99·09. Die Porphyrgesteine Osterreichs, p. 252.

CHAPTER VII.

GROUP B. BASIC DIVISION.

Nomenclature.

IN dealing with Group B it will be convenient for purposes of description to separate it into two divisions; the one containing the basic members and the other the intermediate members of the group. The separation is, of course, not sharply defined. The members of the basic division, when mainly composed of crystalline constituents, have a specific gravity of about 2·9, and a silica per centage of about 50. Mineralogically they are characterised by the abundance of ferro-magnesian constituents—olivine, pyroxene, hornblende, &c. The members of the intermediate division are characterised by a silica percentage of about 60, a specific gravity of 2·6 or 2·7, and by the fact that the ferro-magnesian are subordinate to the felspathic constituents. In this chapter we deal with the members of the basic division, and with the corresponding vitreous and semi vitreous rocks.

Many names have been applied to the rocks of this division; such as gabbro, euphotide, norite, hypersthenite, hyperite, forellenstein or troctolite, diorite, corsite, eucrite, augite-diorite, diabase, diabase-porphyrite, labradorite-porphyrite (labrador-porphyr.), variolite, ophite, proterobase, epidiorite, dolerite, anamesite, basalt, greenstone, melaphyre, leucophyre. The glassy and half-glassy representatives of this division have received such names as magma-basalt, Limburgite, pyroxenite, augitite, tachylyte, hyalomelane, sideromelane, palagonite.

In the present work we propose, as already explained, to regard rocks simply as mineral aggregates. Special names, particularly those which refer to the minor features, have, therefore, from our point of view, only a local interest. They become a positive hindrance when any attempt is made to correlate the rocks of different countries and of different geological periods, for it frequently happens that one and the same mineral aggregate is designated by different names in different localities. The only way, as it seems to the present writer, of rescuing petrography from the confusion which arises in consequence of this, is to relegate special names to a subordinate position, and in every case to give instead of, or in addition to the name, a concise petrographical diagnosis. As special names, however, cannot be altogether abolished, it seems desirable to give a brief

account of the manner in which those in common use are now employed by the more important writers.

Gabbro. This is an old Italian name said to have been originally applied to a serpentinous rock containing diallage. It was introduced into general geological literature by L. Von Buch. Zirkel defined it [1] as a coarsely crystalline granular rock, composed of labradorite or saussurite and diallage or smaragdite (variety of hornblende). It is defined by Rosenbusch [2] as a pre-tertiary rock, composed of plagioclase and diallage; and is divided into two groups according to the presence or absence of olivine. The important question which is at present undetermined, is whether diallage should be regarded as an essential constituent of gabbro. Streng,[3] Judd,[4] and others have shown that augite occasionally replaces diallage in rocks that have been unhesitatingly referred to the gabbros. Moreover, the latter observer has shown that one and the same crystalline individual may be augite in one part, and diallage in another. He proposes, therefore, that the term gabbro should be applied generally to the coarse-grained granitic modification of the basic magma, irrespective of the nature of the monoclinic pyroxene. In this sense it will be employed in the present work. In addition to the principal constituents, there are others which may be regarded as accessory, and these may again be subdivided into original and secondary. Amongst the original accessories may be mentioned olivine, a rhombic pyroxene, and probably hornblende; amongst the secondary accessories must be placed "compact" hornblende, as well as the uralitic and actinolitic modifications, zoisite, epidote, albite, and quartz. The secondary accessories mentioned above are especially characteristic of rocks that have been affected by contact and regional metamorphism. They mark a certain stage in that change which may give rise to the formation of hornblende-schist, and become of great importance for the purposes of indicating varietal distinctions. We thus speak of saussuritic, hornblendic, uralitic, and actinolitic gabbros. There are also secondary accessories, (*e.g.* zeolites, chlorite, serpentine, &c.,) due to weathering; and others, (*e.g.* magnetite,) due to the process for which Professor Judd has proposed the term "schillerisation."

Euphotide.—This name was introduced by Haüy for a rock which we should now designate as saussuritic gabbro. It is employed by Messrs. Fouqué and Lévy and by French petrographers generally, for a gabbro of Tertiary age. In this sense there is of course no distinction in composition or texture between gabbro and euphotide. Professor Bonney [5] proposes that, if used at all, it should be employed in its original sense; that is for an altered gabbro.

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(1) Lehrbuch der Petrographie, 1866, Vol. II., p. 10.

(2) Die Massige Gesteine (1st edition), p. 459.

(3) N.J., 1862, p. 943.

(4) Q.J.G.S. Vol. XLII., 1886, p. 61.

(5) Q.J.G.S. Vol. XLI., 1885. Proc. p. 70.

Forellenstein (Troctolite). Is a local name applied to a variety of gabbro occurring at Neurode, in Silesia. It has been extended to similar rocks in other localities. It is coarse-grained and granitic in texture, being composed essentially of plagioclase and olivine or olivine-serpentine. The serpentinised olivines appear as dark spots on a grey groundmass; hence the local name which means trout-stone. The felspar has been described by Von RATH [1] as an altered labradorite, and by STRENG [2] as an altered anorthite. Augite (diallage) occurs as an accessory constituent, so that the rock is merely a gabbro extremely rich in olivine.

Norite.—This name was originally applied by ESMARK [3] to many Norwegian rocks which we should now separate from each other under such heads as diorite and gabbro. SHEERER [4] limited its signification to rocks of the gabbro-type, such as those occurring in the island of Hitteroe. These appear to embrace typical gabbros, and also rocks in which a rhombic pyroxene takes the place of augite or diallage. Professor ROSENBUSCH proposes to limit the term norite to pre-tertiary rocks composed essentially of plagioclase and a rhombic pyroxene. The simultaneous occurrence of rhombic and monoclinic pyroxenes in rocks of the gabbro-type [5] shows that there is no hard and fast line between the gabbros and the norites (ROSENBUSCH). In this work we shall use the term norite in ROSENBUSCH'S sense but without the restriction as to geological age.

Hypersthenite and Hyperite.—These are synonyms of ROSENBUSCH'S norite. Many rocks formerly termed hypersthenites in this country are now known to be gabbros. The present writer is not acquainted with any British norite.

Diorite.—This term was introduced by HAÜY [6] for a rock composed of white felspar and hornblende. It was distinguished from syenite (WERNER) by the greater abundance of the latter mineral. It was employed by ZIRKEL [7] for a crystalline granular compound of oligoclase and hornblende, often associated with quartz. ROSENBUSCH uses it for a similar rock but without reference to the particular species of plagioclase, and divides the diorites into two groups according to the presence or absence of quartz. The quartz-diorites are rocks of intermediate composition and do not, therefore, belong to the group now under consideration. The quartz-free diorites form a very unsatisfactory group so far as at present known. Some of them, including the epidiorites of GÜMBEL, are plagioclase-augite rocks which have been affected by contact and regional metamorphism; others have probably always been plagioclase-hornblende rocks. To the latter belong the diorites of Warwickshire described by Mr. ALLPORT [8] some of which contain olivine, and

(1) P.A. XCV., p. 551.
(2) N.J. 1864. p. 257.
(3) Magazin fur Naturvidenskaberne I, p. 207.
(4) N.J. 1843, p. 668.
(5) See JUDD Q.J.G.S. Vol. XLII., 1886, p. 64.
(6) Traité de Minéralogie. 2nd. edition. Paris, 1822. p. 541.
(7) Lehrbuch der Petrographie, 1866. Vol. II., p. 1.
(8) Q.J.G.S. Vol. XXXV., p. 637.

may therefore be conveniently designated olivine-diorites. The latter stand in close relation with the rocks described by Professor BONNEY as hornblende-picrites.

Corsite.—This name, originally applied to the orbicular-diorite of Corsica, also called Napoleonite, is used by ZIRKEL for any variety of diorite in which the felspar is anorthite or some allied species.

Eucrite.—This name was introduced by G. ROSE. It was subsequently limited by ZIRKEL [1] to a compound of anorthite and augite. Such a rock consisting of 62 per cent of anorthite and 38 per cent of augite, has been described by Dr. HAUGHTON [2] as occurring in the Carlingford district, Ireland. Von LASAULX describes a rock occurring at Rostrevor, County Down, as a eucrite.[3] It consists of plagioclase (labradorite or anorthite), augite, uralite, viridite, magnetite and apatite.

Augite-diorite.—ZIRKEL proposed this name for oligoclase-augite rocks. Mr. COLE [4] has recently suggested that it should be used without reference to the character of the plagioclase.

Diabase.—This term was introduced by A. BROGNIART [5] for rocks which would now be termed diorite. HAUSMANN proposed in 1842 to revive the term, which had been dropped by the consent of its author, for rocks containing hypersthene [augite], labradorite and chlorite.[6] ZIRKEL defines diabase as a rock consisting of labradorite, augite and chlorite. ROSENBUSCH employs the term[7] for a pre-tertiary holo-crystalline massive rock composed essentially of plagioclase and augite. He does not recognise chlorite as an essential constituent, because it can be shown to arise in consequence of the alteration of augite and to be, therefore, a secondary and not an original constituent. He divides the diabases into two groups; diabase proper and olivine-diabase. If we disregard geological age, then ROSENBUSCH's diabase corresponds very closely with our dolerite; the only difference being that the term dolerite does not absolutely exclude the presence of a small amount of interstitial matter.

Diabase-porphyrite, Labradorite-porphyry and Porphyritic-dolerite.—These terms are employed for certain representatives of the basic magma in which porphyritic crystals of labradorite, bytownite or anorthite occur in a dark, fine grained or compact groundmass. The two former are employed on the Continent for pre-tertiary rocks. Professor JUDD has shown that precisely similar rocks of tertiary age occur on the west of Scotland.

Augite-porphyry.—Name applied to a rock containing large crystals of augite. Such a rock occurs as a dyke at Crawfordjohn in Lanarkshire.

Variolite.—A name applied by French petrographers to a compact variety of diabase, characterised by light circular spots on a dark groundmass. The variolitic structure occurs at the margins of certain masses of normal diabase (plagioclase-augite-chlorite rock), and is therefore a contact phenomenon.

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(1) Lehrbuch der Petrographie, 1866. Vol. II., p. 135.
(2) Q.J.G.S. Vol. XII., 1856. p. 197.
(3) T.M.M., Neue Folge. Vol. 1. p. 433.
(4) G.M. Decade III. Vol. III. p. 225.
(5) Jour. des Mines. Tome XXXIV., July, 1813.
(6) Über die Bildung des Harzgebirges, 1842.
(7) Massige Gesteine, 1st edition.

Ophite.—This name has been applied to certain basic igneous rocks occurring in the Pyrennees. The true character and relationships of the different varieties have not been fully worked out. It must therefore be regarded as a local term applied to rocks of somewhat variable character. Plagioclase, augite, diallage, hornblende, and brown mica enter into the composition of these rocks. Where the rocks are largely composed of plagioclase and augite the latter mineral usually occurs in large irregular masses, which include and are penetrated by the felspar prisms. This mode of arrangement (see Plate X., Fig. 1.) has been designated by M. LÉVY as the ophitic, and the term is used in this sense in the present work.

Proterobase.—This term is due to GÜMBEL.[1] The rock consists of green or brown, not strongly fibrous hornblende, reddish brown augite, plagioclase, a chloritic mineral, magnetite or ilmenite, and in most cases a magnesian mica. Some of the proterobases of GÜMBEL have been shown by LOSSEN [2] and LIEBE [3] to be normal plagioclase-augite rocks (diabase,) altered by contact and pressure-metamorphism. Thus, a rock from Winzenberg in the Hartz, described by ROSENBUSCH as a typical proterobase has been shown by LOSSEN to be a normal diabase altered by contact with granite. Precisely similar rocks have been described by Mr. ALLPORT [4] in his classic paper "On the Metamorphic Rocks surrounding the Land's End Mass of Granite."

Epidiorite (GÜMBEL).—The rock is defined as a mixture of fibrous, pale green needle-shaped hornblende, often much altered, plagioclase, a chloritic mineral and ilmenite or magnetite. Augite is absent, or present only in very small quantity. According to LIEBE (loc. cit.) the epidiorites are diabases that have been affected by regional metamorphism. They occur in the zone of maximum metamorphic action.

Leucophyr (GÜMBEL).—This rock is distinguished from normal diabase by its pale colour, due to the predominance of the felspathic constituent. It is defined by GÜMBEL as consisting of a saussuritic plagioclase, pale green augite (without hornblende, and rarely with reddish brown augite) in very small quantity, a chloritic mineral and ilmenite. ROSENBUSCH refers certain rocks intercalated with the Steiger Schiefer of the Vosges to GÜMBEL's leucophyre. [5]

The epidiorites, proterobases and leucophyres of GÜMBEL are all associated with lower palæozoic sediments, and appear to have been involved with the

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(1) Die palæolithischen Eruptiv-gesteine des Fichtelgebirges, Munich, 1874, p. 9.

(2) Studien an metamorphischen Eruptiv- und Sediment-gesteinen. Jahr. d. k. Preuss. Geol. Landesanstalt, 1883, p. 619. Über das Auftreten metamorphische Gesteine in den alten paläozoischen Grebigskernen von der Ardennen bis zum Altvatergebirge und über der Zusammerhang dieses Auftretens mit der Faltenverbiegung (Torsion) Sits. d. Ges. natur. Freunde, Berlin, 1885, p. 32.

(3) Übersicht über der Schichten-aufbau Ostthuringens. Abhand. z. geo. Specialkarte v. Preussen u. d. Thüring. Staaten. Bd. V., Hft. 4.

(4) Q.J.G.S. 1876, XXXII., p. 407.

(5) A specimen from the Vosges labelled Leucophyre, Breitenbach, in the author's possession, contains uralitic and actinolitic hornblende of a pale green colour, but is entirely destitute of augite. The felspar in many places is perfectly colourless, and occurs in irregular granular aggregates. The rock, in short, has not the microstructure of a normal igneous product, but gives evidence of having been subjected to contact on pressure metamorphism. It seems probable therefore that in this case we are dealing with a plagioclase-augite rock which has been involved in the earth movements that have affected the sediments with which it is associated.

latter in the earth movements that have affected the districts in which they occur. Corresponding rocks are found in this country in Devon and Cornwall.

Dolerite.—This name was applied by Haüy to a rock essentially composed of augite and plagioclase. The type rock from Meissner contains also a little olivine. Rosenbusch uses the term as subordinate to basalt, and merely employs it for a coarse grained variety of the latter rock. It is, therefore, according to Rosenbusch a post-cretaceous rock composed essentially of plagioclase, augite and olivine. Mr. Allport [1] has proposed that dolerite should be raised to the rank of a group name; that it should be used without reference to geological age; and that it should be employed for all basic igneous rocks essentially composed of plagioclase and augite, and possessing a texture intermediate between gabbro and basalt. From this point of view olivine is not regarded as an essential constituent. In this work we shall follow Mr. Allport. The term dolerite will be applied to a medium grained plagioclase-augite rock of basic composition. The different varieties depending on the presence of certain accessory constituents will be termed olivine-dolerite, enstatite-dolerite, mica-dolerite, hornblende-dolerite, &c.

Anamesite.—This term was introduced by Leonhard for the finer grained but distinctly crystalline members of the dolerite group.

Basalt.—This is a very old term first used by Strabo and Pliny for certain black rocks from Egypt, which were employed in the arts in very early times. Cordier proved in 1815 by the microscopic examination of the powder of the compact rocks to which the term had been applied in Europe, that these rocks resembled dolerite in mineralogical composition. In 1870 Zirkel [2] separated the continental basalts into three main groups—felspar-basalts, nepheline-basalts and leucite-basalts. In 1877 Rosenbusch proposed to make olivine an essential constituent of basalt, and defined basalt as a post-cretaceous rock essentially composed of plagioclase, leucite or nepheline with augite and olivine. Basalt is used by Rosenbusch as the group name, and dolerite is applied to a coarsely crystalline basalt. As in this country the distinctly crystalline varieties prevail over the compact forms, we take dolerite as the group name.

Greenstone.—This is an old term which has been applied to many of the basic igneous rocks associated with palæozoic and especially with lower palæozoic sediments. The green colour is due either to chlorite or hornblende. The word has done good service in the past as a field term and, where it is impossible to give a precise mineralogical description, is not without its use at the present day. Many of the old greenstones are dolerites altered by surface agencies (diabases), or by contact or regional metamorphism (epidiorites and proterobases). Diabases abound in Wales and epidiorites and proterobases in Devon and Cornwall.

Melaphyre.—This term was introduced by A. Brogniart for rocks consisting of a "pâte noire d'amphibole petrosiliceux envellopant des crystaux

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(1) Q.J.G.S., vol. XXX., p. 529.

(2) Über die Mikroskropische Zusammensetzung und Structur der Basaltgesteine. Bonn, 1870.

de felspath." Such a definition is of course of little use in fixing the meaning of the term as used at present. ZIRKEL [1] defines melaphyre as a rock consisting essentially of oligoclase and augite. At the time this definition was given there were no satisfactory determinations of the felspars, and all that it can be taken to imply is that the melaphyres as a group were more acid than the diabases and dolerites, which were described as composed of labradorite and augite. ROSENBUSCH defines melaphyre as a pre-tertiary massive rock composed essentially of plagioclase, augite and olivine, together with a certain amount of interstitial matter. The melaphyres according to this definition are the precise equivalents of the basalts of the same author; the only difference being one of age. The presence of interstitial matter is made the point of distinction between melaphyre and olivine-diabase.

Magma-basalt.—Name used by MÖHL and BÔRICKY [2] for a rock having the chemical composition of basalt, but consisting only of augite, magnetite and glass. Felspars absent, or if present occurring only in extremely small quantity.

Limburgite.—Name introduced by ROSENBUSCH [3] for a rock composed of augite, magnetite and glass; that is for a non-felspathic rock of basic composition.

Pyroxenite.—Name proposed by DOELTER [4] for a rock composed of augite, magnetite and glass. In this sense it is synonymous with BÔRICKY's magma-basalt. The term pyroxenite has been used in different senses by different writers, and it has therefore been proposed that the term *augitite* should be substituted for *pyroxenite* (DOELTER).

Tachylyte.—Name introduced by BREITHAUPT in 1826 for what is now known to be the glassy modification of the basic magma.

Hyalomelane.—Name introduced by HAUSMANN in 1844 for a substance supposed to be distinct from tachylyte. It is now admitted that there is no valid distinction between hyalomelane and tachylyte, and the former name is therefore dropped in favour of the latter.

Sideromelan.—Name introduced by Von WALTERSHAUSEN in 1853 for a tachylyte, from Iceland, which formed the anhydrous kernels of the same author's *palagonite.*

Palagonite.—Name introduced by Von WALTERSHAUSEN for a substance now generally regarded as being formed from basalt-glass (tachylyte) by oxidation and hydration.

CHARACTERS OF THE ROCK-FORMING MINERALS.

Felspar. Orthoclase is probably very rare as a constituent of the rocks of this group. It is constantly mentioned as occurring by the earlier writers on microscopic petrography; but it must be remembered that the presence of

(1) Lehrbuch der Petrographie. Vol. II. p. 39.
(2) Studien an den Basalt-gesteinen Böhmens. Prag. 1874.
(3) N.J., 1872. p. 35.
(4) Die Vulkane der Capverden. Graz 1882.

simple individuals, or binary twins, was regarded, for a long time, as sufficient evidence of its existence. It is now known that these characters are frequently possessed by the different varieties of plagioclase. The most valuable tests for the determination of orthoclase in thin sections are (1) straight extinction in sections giving rectangular outlines, that is in sections of the zone 100 : 001 ; and (2) simultaneous extinction in the two halves of a binary twin (Carlsbad) when the trace of the face of composition lies parallel with the short axis of one of the nicols. The latter character shows conclusively that the section is one of orthoclase cut at right angles to the clinopinacoid (010). Of course many sections of Carlsbad twins of orthoclase split up under crossed nicols into two halves which do not extinguish simultaneously, but these never show symmetrical extinction with reference to the trace of the composition-face. It therefore follows that symmetrical extinctions in sections which show normal twinning, whenever they occur, imply that the felspar is triclinic.

Chemical analyses show that potash, in small quantities, is a normal constituent of basic rocks. This fact does not, however, prove the independent existence of a potash felspar, as the substance may enter into the composition of a triclinic species belonging to the soda-lime group. Indeed, chemical analyses and flame reactions constantly show the presence of a small amount of potash in the soda-lime felspars. Although we cannot at present speak positively as to the occurrence of orthoclase in the ordinary basic rocks of Britain, there can be no doubt that it exists in the so-called contemporaneous or exfiltration veins in such rocks. Thus, Mr. Waller has shown [1] that certain red and grey veins in the Rowley Rag dolerite are mainly composed of felspar occurring as simple individuals or binary twins, and that the two halves of the latter often extinguish simultaneously when the length of the section and the trace of the composition-face are parallel with the short axis of one of the nicols. He has further proved by chemical analysis that the rocks of these veins contain a much higher percentage of silica (58 as against 48 p.c.), and also a much larger amount of potash. We have now to consider the dominant felspars of the basic group of rocks. These may be either primary or secondary ; the latter, however, are only known in rocks that have been affected by contact or regional metamorphism. The primary or original felspar may occur (1) as porphyritic crystals with more or less definite form, or as fragments of such crystals, (2) as porphyritic granular aggregates, (3) as small columnar crystals, giving lath-shaped sections, (4) as irregular grains, and (5) as skeleton crystals and microlites.

The porphyritic crystals are usually somewhat tabular in form, with conspicuous development of the brachypinacoid, M (010). The other common faces are P (001), l (110), T ($1\bar{1}0$), and x ($\bar{1}01$). The curious form which is characteristic of the rhomben-porphyr of Norway, in which the faces T, l and y ($\bar{2}01$) are alone developed, is not known in any British rock, and seems, indeed, limited to rocks exceptionally rich in alkalies.

The porphyritic and other felspars of the rocks under consideration are usually twinned. The most common type of twinning is that known as the

(1) Midland Naturalist. Vol. VIII. 1885, p. 261.

albite-type. The twin axis in this case is normal to the brachypinacoid (010) which plane is also the face of composition. The larger felspars are frequently composed of a number of lamellæ due to repeated twinning on the albite plan, and it is this feature which produces the well-known striation on the plane of easiest cleavage (001). Sections at right angles to (010) always give symmetrical extinctions on opposite sides of the trace of the twin-plane, which in this case is also the composition face. It will subsequently be shown that the observation of a number of such extinctions gives some information as to the particular species of felspar under examination. Next to the albite type of twinning, that known as the pericline type is the most common. In this case the twin-axis is the *b* axis of the crystal, and the effect of repeated twinning is to produce a striation on the clinopinacoid. It has been shown by VOM RATH that this striation makes different angles with the edge P/M (001 : 010) in the different species of plagioclase. Not seldom the albite and pericline types co-exist in one and the same crystal.

In addition to the albite and pericline types of twinning, one frequently observes a third type corresponding with the well-known Carlsbad type of the monoclinic felspars. In this case the vertical axis of the crystal is the twin-axis, and the brachypinacoid forms the face of composition. Sometimes, as in the large porphyritic crystals of the dolerite (diabase-porphyrite) of EYCOTT HILL one sees that the main individual is composed of two halves due to twinning on the Carlsbad plan, and that each half is again composed of smaller lamellæ due to simultaneous twinning on the albite plan. As, in twinning on the Carlsbad and albite plans, the face of composition is usually in both cases the brachypinacoid, it is not at first sight easy to recognise in sections whether one or both types of twinning are present. On testing the extinctions, however, it will always be found that if the albite type only be represented, then the odd lamellæ all extinguish in one position, and the even lamellæ in another position. In other words there are only two positions of extinction, as it were, for the entire section. If the section illustrates simultaneous twinning on the Carlsbad and albite types, it will be found in general that the above rule does not hold. It will be necessary to place the section in more than two positions in order to extinguish all the lamellæ. This simultaneous twinning is frequently found in the porphyritic crystals of the rocks now under consideration. In addition to the albite, pericline and Carlsbad types of twinning, there are others which are, however, too complicated to be considered in the present work.

The porphyritic crystals often show a zonal structure due to inclusions, or to a variation in the optical characters of successive zones. In the former case it is frequently observed that the distance between contiguous zones is greater in the direction of the length than in that of the breadth of the crystal-section; a fact which testifies to the unequal rate of growth in different directions. Sometimes the inclusions of the groundmass are very irregular in their form and distribution, and so numerous that the crystal appears completely honeycombed by them. This feature is, however, more characteristic of the rocks of intermediate composition—the andesites and porphyrites—than of those now under consideration. Where the zonal structure is due to a variation in

the optical characters of different portions, it is generally found that the inner zones are more nearly allied to anorthite than those which form the exterior.

Another feature of considerable interest is this. The inner zones are frequently not bounded by sharp angles, whereas the external and therefore last-formed zones often show a gradual approach to definite crystalline form. This seems to show that the conditions under which the development of the porphyritic crystals commenced were not favourable to the production of definite form, but that they became more and more favourable as the growth progressed. Now, as already stated, there is reason to believe that the porphyritic crystals of volcanic rocks have been brought up from below, and if so this implies that the initial stages of crystalline growth took place under conditions more or less similar to those under which plutonic rocks were produced. The absence of sharp angles in the nuclei of zonal felspars corresponds with this view; for, as will be shown later on, the felspars of the gabbros often occur as irregular grains and coarse granular aggregates. Consolidation under great pressure appears therefore in many cases to be unfavourable to the development of crystalline form.

The porphyritic felspars have often been broken and deformed by mechanical forces connected with the movement of the magma in which they were developed; and in some cases the magma appears to have exercised a corrosive effect upon them.

In addition to the large porphyritic crystals one usually observes a number of small columnar crystals which give lath-shaped sections. In a large number of basic rocks these occur to the exclusion of the former. They are usually so small that nothing definite can be made out with reference to them except by the use of the microscope. They are frequently referred to in descriptions of microscopic sections as lath-shaped felspars; but of course this mode of expression is not strictly accurate, as the term *lath-shaped* has reference to the appearance of the most striking sections and not to the form of the felspar. The long axis of these small columnar crystals lies parallel with the edge P/M, and the terminal faces are often ill-developed. Twinning on the albite plan is usually, though not always present. Binary twins are not uncommon, and these have often been taken to indicate the presence of orthoclase. Inclusions and zonal banding are usually absent from the small columnar crystals.

In the more coarsely crystalline rocks of the basic group the felspars are frequently present in the form of irregular grains without any marked approach to definite crystalline form. This is especially the case in those rocks which exhibit the granitic texture in the greatest perfection; as, for example, certain gabbros and norites. Sometimes, however, in these rocks large portions of the felspar give definite extinction and include numerous crystals or crystalline grains of the other constituents (see Plate III., Fig. 2.)

Liquid inclusions with moveable bubbles are frequently present in great numbers in the felspars of the plutonic rocks of the basic group. They have

been especially recorded by ZIRKEL[1] and JUDD[2] as occurring in the gabbros of the west of Scotland. They occur in fissures or bands parallel to fissures, and are often connected by minute ramifying tubular processes. The same felspars often contain the minute black rods and plates which have been already referred to (page 28) as occurring along definite planes within the crystal.

In some of the rocks of the basic group which exhibit a well marked trachytic texture the porphyritic elements in the rock are not simple crystals, or fragments of such crystals, but granular aggregates to the external surfaces of which felspar-substance has been added so as to produce definite external form. This is well seen in the porphyritic portion of the Tynemouth Dyke.[3]

In this case granular aggregates of a felspar allied to anorthite have been completed externally by felspar-substance having optical characters somewhat different from those of the principal mass. This substance has doubtless been added during the later stages of consolidation, and is possibly contemporaneous with the felspars of the groundmass. The individual grains of what may be termed the primary aggregate are related to each other in exactly the same way as the grains in many typical gabbros. It seems reasonable therefore to suppose that the aggregates were formed under plutonic conditions; that they were then broken up and carried forward by movements taking place after consolidation had progressed to a certain extent; and that the external zone, which determined the crystalline faces, was added during one of the latter stages in the process of consolidation.

Professor JUDD describes and figures under the name of glomero-porphyritic structure a very interesting feature which occurs in the dolerite of Fair Head, Co. Antrim. In this case granular aggregates of anorthite and olivine occur as porphyritic elements in a groundmass which may be described as an ophitic olivine-dolerite.[4]

Felspar in the form of microlites and skeleton crystals occurs in those rocks which contain a considerable amount of glass or other interstitial matter. The precise determination of the felspars of the coarse-grained rocks and of the porphyritic felspars of the fine-grained rocks is best effected either by the observation of the optical characters presented by cleavage flakes; by SZABO's method depending on the simultaneous observation of flame colouration and fusibility; by the determination of the specific gravity; or by micro-chemical tests. It can only be made with certainty in ordinary thin slices by the recognition of a section whose direction can be definitely determined by a study of the cleavage cracks, external form, or the relation

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(1) Geologische Skizzen Von der Westküste Schottlands. Z.D.G.G., Vol. XXIII., (1871), p. 59.

(2) On the Tertiary and Older Peridotites of Scotland. Q.J.G.S., Vol. XLII., (1885), p. 375,

(3) TEALL. North of England Dykes, Q.J.G.S., 1884, p. 247 and Plate XIII., Fig. 1.

(4) Q.J.G.S., 1886, Plate VII., Fig. 3.

of the twin lamellæ. In the majority of cases this is impossible. The fact that only a small number of sections of the larger felspars are usually available for examination renders the statistical method of M. Lévy of little use in the precise determination of these felspars. Nevertheless, if a section can be found in which twinning on the albite plan occurs, and in which the extinctions are symmetrical with reference to the trace of the twinning plane; then, if the extinctions between two lamellæ exceed 37°, the existence of labradorite, bytownite or anorthite may be inferred, and if the extinctions exceed 62° one of the two latter minerals must be present.[1]

In the case, however, of the larger felspars it is in most cases easy to obtain cleavage flakes, and then a precise determination may be effected by the method of Des Cloiseaux. To obtain cleavage flakes a portion of the rock may be roughly powdered, grains of the felspar picked out and these grains again broken on a small anvil. From the powder thus produced cleavage flakes may be selected and examined in parallel and convergent polarised light. In most cases the felspars are twinned on the albite plan and this allows the flakes parallel to the basal plane (P or 001) to be easily recognised. Flakes parallel to the brachypinacoid (M or 010) show no twinning when the albite type is the only one present, and they are often rhomboidal in form, the edges being determined by the perfect cleavage parallel to P, and the less perfect cleavage parallel to a prism face of the crystal. These latter flakes are the most useful for the purpose of determining the nature of the felspar by optical methods, as they enable one to ascertain the *sign* of the extinction in Schuster's sense as well as the amount.

The optical characters of the plagioclase felspars of the soda-lime group have been investigated in great detail by Des Cloiseaux[2] and Schuster.[3] The accompanying figure taken from Dr. Schuster's paper will explain the nomenclature which he has introduced, and which is now adopted by common consent in referring to the optical characters of the felspars.

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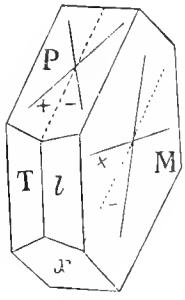
(1) The following are the extinctions in the zone perpendicular to the brachypinacoid (010) for the principal felspars according to Mm. Fouqué and Lévy. Sections in this zone are recognised by the fact that the extinctions of the two adjacent lamellæ of a felspar twinned on the albite plan are symmetrical with reference to the trace of the plane separating the lamellæ: —

	Extinctions referred to the trace of 010.	Extinction angle between two adjacent lamellæ.
Microcline	0° to 18°	0° to 36°
Albite	0° to 15°45′	0° to 31°30′
Oligoclase	0° to 18°30′	0° to 37°
Labradorite	0° to 31°15′	0° to 62°30′
Anorthite	0° to 37°21′ (and over) ...	0° to 74°42′ (and over)

(2) Sur les propriétés optiques biréfringentes caractéristique des quatre principaux felspaths tricliniques. Ann. d. Chimie et d. Physique. 5 serie. t. IV. 1875.

(3) Die optische Orientirung der Plagioclase. T.M.M. Neue Folge, vol. III. p. 117.

This figure represents a plagioclase crystal made up of the following forms: P=(001), M=(010), T=(1$\bar{1}$0), l=(110), x=($\bar{1}$01). It is placed



so that the prismatic zone is vertical, and the basal plane (P) inclined from left to right. The obtuse edge P/M is therefore situated to the right of the observer. The planes of easy cleavage are of course parallel to P and M; there is also a cleavage parallel to T which is often sufficiently marked to determine the form of cleavage flakes parallel to M. Now Schuster has proposed that the signs + and − should be used in a conventional sense for the purpose of defining the directions of extinction on the two principal cleavages. The precise manner in which the signs are used is evident from the figure and therefore needs no further illustration. In cleavage flakes parallel to P, prepared by roughly breaking up the crystals as they occur in rocks, it is not as a rule possible to determine the sign of the extinction; but in those parallel to M it is often possible, because these are frequently in the form of parallelograms, the edges of which are determined by the easy cleavage P and the imperfect cleavage T. On referring to the figure it will be seen that when the direction of extinction, as it may be called, lies in the obtuse angle of the parallelogram the sign is positive, and when it lies in the acute angle the sign is negative.

The researches of Schuster have established the fact that in the normal plagioclase felspars which may be regarded as isomorphous mixtures of albite and anorthite, the optical and chemical characters stand in the closest possible relation to each other. The specimens which have been examined both optically and chemically are not perhaps sufficiently numerous to prove that an absolutely continuous series exists, but they are certainly sufficient to establish the existence of many felspars intermediate between the common types known as albite, oligoclase, labradorite, and anorthite, and therefore to render the theory of Tschermak in the highest degree probable. Thus, the existence of felspars between oligoclase and labradorite (andesine), and between labradorite and anorthite (bytownite) which are intermediate in their optical as also in their chemical characters appears to be definitely established.

Accepting, therefore, the views of Tschermak and designating the albite molecule (Na_2O, Al_2O_3, 6 SiO_2) by *Ab* and the anorthite molecule (2 CaO,

$2\,Al_2O_3, 4\,SiO_2$) by *An* we have the following scheme for the plagioclase felspars.

Ab	Albite		
Ab to Ab_3An_1 ...	Oligoclase, Anorthite rises to	...	26·2 per cent.
Ab_3An_1, to Ab_1An_1 ...	Andesine	...	51·5 „
Ab_1, An_1, to Ab_1, An_3	Labradorite	...	76·1 „
Ab_1, An_3, to *An* ...	Bytownite	nearly	100·0 „
An	Anorthite		

The chemical compositions of the above mixtures are as follows :—

	Ab.	Ab_3An_1.	Ab_1An_1.	Ab_1An_3.	*An.*
SiO_2	68·6	61·9	55·4	49·1	43·0
Al_2O_3	19·6	24·2	28·5	32·8	36·9
CaO	0·0	5·2	10·4	15·3	20·1
NaO	11·8	8·7	5·7	2·8	0·0

The extinction angles on the two principal cleavages referred to the edge P/M, according to SCHUSTER's researches, are :—

Ab, extinction on P	+	4°30′	on M	+	19° 0′
Ab_3An_1,	+	1° 4′	„	+	4°36′
Ab_1An_1,	−	5°10′	„	−	16° 0′
Ab_1An_3,	−	17°40′	„	−	29°38′
An,	−	37° 0′	„	−	36° 0′

The observation of cleavage flakes in convergent light is often of great use in the determination of felspars, and will sometimes yield valuable information when the boundaries of the flakes are not sufficiently well defined to enable a precise determination of the extinction to be made. Examined with the ordinary arrangement for the use of convergent polarised light, with a petrographical microscope, a flake of anorthite parallel either to M or P shows an optic axis within the field of view, but near the margin; a flake of bytownite shows an optic axis close to, but not within the field. A flake of labradorite parallel to M shows a positive bisectrix, very oblique to the axis of the instrument, and one of the axial shadows. In oligoclase and andesine the M cleavage is nearly at right angles to the positive bisectrix. In albite it is oblique to the bisectrix. The observations in convergent light are mainly useful in distinguishing between anorthite, bytownite and labradorite; a single glance at the interference figure is sufficient to show to which of these any given felspar is most nearly allied.

The determination of the felspar by optical methods may be checked by

the use of SZABO's method,[1] or by the determination of the specific gravity. For the latter purpose one of the heavy solutions must be used. A solution must be obtained by careful dilution, in which several small grains of the felspar will remain supended, and then the specific gravity of the solution must be obtained by the ordinary methods. This will of course represent the specific gravity of the felspar. The average specific gravities of the more important felspars are as follows:—albite, 2·62; oligoclase, 2·64; andesine, 2·65; labradorite, 2·69; bytownite, 2·71; anorthite, 2·75.

So far we have been dealing only with those felspars which are sufficiently large to be isolated, and separately examined, and we have seen that various methods have been devised by which a fairly exact determination of such felspars may be made. In the finer grained and compact rocks we constantly find minute felspars which can only be examined in thin section. The above methods are therefore quite unsuitable for the determination of these, and we have therefore to fall back upon the statistical method of M. LÉVY. These small felspars occur as a rule in the form of columns, elongated in the direction of the edge P/M, and twinned on the albite plan. As a consequence of this it follows that the longitudinal, or lath-shaped sections are those which are most marked under the microscope, and these sections are of necessity taken approximately out of the zone P/M. Now the extinctions in this zone vary within certain limits which are different for the different felspars. M. LÉVY gives these limits as follows:—

	Extinction referred to the length of the microlites.	Extinction angle between two lamellæ of a felspar twinned on the albite plan.
Albite ...	0° to 19°	... 0° to 12°
Oligoclase ...	0° to 2°	... 0° to 3°
Labradorite	0° to 17° or 27°	... 0° to 18
Anorthite ...	0° to 30° (and over)	... 0° to 40° (and over)

The data on which these figures are based, and the method adopted in the calculation do not permit of absolute accuracy.[2] Nevertheless, the results show that microlites of oligoclase must in all cases extinguish approximately parallel with their length, and that felspars giving high extinction angles must belong to the labradorite-anorthite group. The application of this method requires of course the observation of a considerable number of sections as the maximum extinction is the only one on which any conclusion can be based. Moreover the existence of felspars intermediate between the species recognised by M. LÉVY complicates the matter very considerably. Again, the presence of a felspar giving high extinction angles does not necessarily exclude other felspars giving lower angles, and these of

(1) It would be out of place here to describe this method. An account of it will be found in the Proceedings of the American Association for the Advancement of Science, vol. XXXI. Montreal Meeting, 1882. See also "Über eine neue methode die Felspathe auch in Gesteinen zu bestimmen," Buda Pesth. 1876. It is a very simple and rapid method for the determination of the felspars. Orthoclase, soda-orthoclase, albite, oligoclase, labradorite and anorthite may be readily distinguished form each other; the experiment in each case not lasting more than a quarter of an hour.

(2) See Schuster, T.M.M., Neue Folge, Band III., p. 273.

course cannot be detected by the method under consideration. The general conclusion, therefore, at which we arrive, is that the determination of the precise character of the minute felspars in rocks is in most cases impracticable. All that we can say is that those which give lath-shaped sections and very low extinction angles are allied to oligoclase, and those which give similar sections and high extinction angles are allied to labradorite and anorthite.

We have now to consider the distribution of the different varieties of plagioclase in the different classes of basic igneous rocks. As we should naturally expect, the original felspars of the basic rocks are of a basic character. Anorthite has been analysed by Dr. Haughton from a plagioclase-augite rock (eucrite) from Carlingford, County Down; and Dr. Heddle gives an analysis of an altered anorthite from the gabbro of Lendalfoot, in Ayrshire. Typical anorthite appears, however, to be comparatively rare, the most common felspar being one intermediate in composition between anorthite and labradorite. Tschermak and Schuster use the term bytownite for such a felspar. In the coarse-grained granular rocks, belonging to the gabbro-family, the plagioclase occurs in the form of grains of tolerably uniform dimensions in the different directions, or as large crystalline plates, containing inclusions of other minerals, especially olivine. It shows broad lamellar twinning on the albite, and less frequently on the pericline plan.

In porphyritic rocks belonging to the dolerite-family it occurs as individual crystals and as crystalline granular aggregates, which are sometimes completed externally, as in the Tynemouth dyke [1] by felspar-substance of a composition somewhat different from that forming the interior portions of the grains. The following list of analyses will give an idea of the composition of the felspars of the basic eruptive rocks of Great Britain and Ireland.

	I.	II.	III.	IV.	V.	VI.
SiO_2 ...	45·87	47·30	49·155	50·811	52·411	53·60
Al_2O_3 ...	34·73	31·50	29·620	29·480	28·959	29·88
Fe_2O_3 ...	—	1·85	1·152	0·252	0·149	0·20
MnO ...	—	—	—	—	0·913	—
MgO ...	1·55	0·93	0·911	0·124	0·54	0·07
CaO ...	17·10	14·88	15·309	12·690	10·85	11·02
K_2O ...	—	0·38	0·695	·552	1·61	0·80
Na_2O ...	—	1·22	2·914	3·922	3·485	4·92
H_2O ...	—	1·80	·730	2·481	·93	·48
	99·25	99·86	100·486	100·312	99·847	100·97

I. Anorthite from Eucrite of Carlingford. Dr. Haughton. Phil. Mag. Series IV. Vol. XIX., 1860, p. 13.

II. Bytownite occurring as porphyritic granular aggregates in the Tynemouth Dyke. Mr. Stead. Q.J.G.S., Vol. XL., 1884, p. 234.

III. Bytownite from Gabbro, Hart O'Corry, Skye. Dr. Heddle. Trans. Roy. Soc. Edin. Vol. XXVIII., 1879, p. 253.

(1) See Teall, Petrological Notes on some North of England Dykes, Q.J G.S, Vol. XL. 1884. p. 233.

IV. Labradorite from gabbro, Loch Scavaig, Skye. Dr. Heddle *(loc. cit.)*
V. Labradorite from diorite, Portsoy. Dr. Heddle *(loc. cit.)*
VI. Labradorite from gabbro, Loch Scavaig. Dr. Haughton. Dublin Quart. Jour. Sci., Vol. V., 1865, p. 94.

We have at present no very precise determination of the felspars of the finer grained non-porphyritic rocks belonging to the dolerite-family. The ophitic dolerites or, in other words, the plagioclase-augite rocks in which the felspar is present in elongated columnar crystals, and the augite in large irregular crystalline masses [1] are very common, both amongst the palæozoic and tertiary igneous rocks of this country, and there is no reason to doubt that the felspars of these rocks are identical with those of the corresponding rocks on the Continent. The dominant felspar of the ophitic dolerites (diabases) of the Hartz have been shown by Schilling [2] to be typical labradorite, composed of two molecules of anorthite and one of albite ($Ab_1 An_2$).

There can be no doubt, therefore, that the prevailing felspars in the basic division of the normal plagioclase rocks belong to the labradorite-anorthite group. At the same time there is evidence that felspars more nearly allied to albite are present in certain members of the group, especially those which occur on the border line between the rocks of normal basic and those of normal intermediate composition. The Whin Sill may fairly be classed as a member of the basic family, for it possesses a silica per-centage of about 50 and a specific gravity over 2·9. A consideration of the analysis of the impure felspar substance, extracted from this rock by the specific gravity method, points to the conclusion that the original felspar was andesine. [3] This rock, although it occasionally shows traces of the ophitic texture, does not possess this texture in anything like the same degree of perfection as the dolerites in which the felspar is known to be labradorite. Another point of importance in relation to this rock is the presence of the bisilicate, enstatite, in the place of the unisilicate olivine. Dr. Hawes has shown that the isolated felspars of the rock from Jersey City which possesses many points of resemblance to the Whin Sill, can be separated into two portions, the one having a specific gravity greater than, and the other less than 2·69. The former on analysis proved to be labradorite and the latter andesine. [4]

The occurrence of oligoclase in the rocks of the basic division is certainly rare. Nevertheless the microlitic felspars of certain trachytic representatives of this division give approximately straight extinction in all longitudinal sections, and may therefore be referred to this species. Albite is not known to occur as an original constituent, but appears to be frequently present, as a secondary product, in those rocks that have been affected by regional metamorphism. Orthoclase has already been mentioned as a constituent of certain "exfiltration" or "contemporaneous" veins in the olivine-dolerites of Rowley Regis in Staffordshire. Dr. Geikie mentions the occurrence of

(1) Structure *diabasich-koring* (Rosenbusch) and *divergent strahlig* (Lossen).

(2) Grunsteine des Harzes. Gottingen, 1869.

(3) Teall. Q.J.G.S., Vol. XL., p. 642.

(4) Proceedings of U. S. Natural History Museum, 1881, p. 129. N.J., *Ref.*, 1882, Band I., p. 414.

orthoclase as a constituent of certain diabases in the Midland Valley of Scotland.

The alteration of the felspars of basic igneous rocks by the various metamorphic agencies is a subject of great interest and importance. At the same time it is one of considerable difficulty. This difficulty is due, partly to the difficulty of determining the precise nature of the alteration products, and partly to our ignorance of the conditions under which the various products arise. The modification of the felspars by surface agencies gives rise, under certain circumstances, to the formation of zeolites, of which prehnite, natrolite and analcime are the most common. Under other circumstances, the felspar is destroyed without the formation of zeolites, the ultimate product of alteration being, in this case, a hydrated silicate of alumina from which the lime has been wholly, and the soda and silica partially removed. Calcite and quartz are frequently formed in veins and cavities in the rocks in connection with this change. The decomposition of the felspar is of course usually affected in conjunction with that of other minerals, so that the conditions become complicated by the presence of solutions of various salts, and new minerals, containing elements not present in the original felspar are thus frequently formed. In this way the magnesian silicates, such as chlorite and pseudophite, which frequently occur as pseudomorphs after felspar may be accounted for. Professor PUMPELLY[1] has pointed out that, in the basic igneous rocks, the formation of chloritic pseudomorphs after felspar is often preceded by the devolpment of prehnite. The comparative insolubility of alumina prevents, as a rule, the removal of this substance. Nevertheless, the presence of the more powerful acids, and especially sulphuric acid, may give rise to the formation of soluble compounds of this base.

Of the various substances which arise in connection with the alteration of the felspars of basic igneous rocks, the so-called saussurite is undoubtedly one of the most important. The term *saussurite* was applied by SAUSSURE to a tough, compact or fine grained light coloured substance, possessing the hardness of quartz, and a specific gravity of from 3·32 to 3·4, and which, together with smaragdite, made up the rock for which HAÜY proposed the name euphotide. The name was introduced under the impression that the substance was a definite mineral. Subsequent researches have shown that this is not the case. At the same time the term is one which it is found extremely convenient to retain. Many varieties of saussurite have been analysed, with the general result that the substance is found to vary considerably in composition. The silica ranges from 43 to 50 per cent.; the alumina from 25 to 32 per cent; the lime from 10 to 18 per cent; and the soda from 1 to 5 or 6 per cent. Variable quantities of iron, magnesia and water occur. Dr. STERRY HUNT investigated the chemical and physical properties of the saussurite of certain Swiss gabbros or euphotides. He described it as compact and tough, with a splintery fracture, and of a whitish, greenish, bluish or reddish colour. It contained lamellæ of triclinic felspar and actinolite. Specific Gravity 3·3, Hardness 7. In chemical

(1) On the metasomatic Devolopment of the Copper-bearing rocks of Lake Superior. Proc. Amer. Acad., 1878. p. 253.

composition it possessed affinities with meionite or zoisite, and Dr. HUNT considered that certain varieties might be regarded as compact zoisite.

In 1883, CATHREIN [1] published an account of some elaborate chemical and microscopical researches into the nature of certain saussurites. He found that by the use of very thin sections and a magnifying power of 300 diameters the substance, which appeared cloudy and indistinct when viewed in thick sections and with low powers, could be resolved into distinct minerals. Thus, in one variety, prismatic microlites and irregular grains of a colourless or greenish strongly refracting mineral were seen to lie embedded in a clear groundmass. The prismatic microlites showed a six-sided cross-section, and were often terminated by two planes meeting in a roof-like manner. The prisms showed transverse jointing and a cleavage parallel to their length. They gave straight extinction and their outlines were strongly marked, thus indicating a mineral with high refractive index. The faces of the prisms were in some cases so well developed as to admit of the measurement of the principal angles. The crystallographic forms represented were u (021), m (110), b (010) and a (100). The angles were u : u = 69° ; u : b = 55° ; m : m = 64°.

Now, as these angles and all the other characters above mentioned agree with zoisite, there can be no doubt that the prismatic microlites belong to this mineral. The colourless groundmass in which the zoisite-prisms are embedded occurs in the form of irregular grains which sometimes show the twin structure of plagioclase.

In some of the saussurites examined by CATHREIN the prismatic crystals were yellowish green, and possessed a marked pleochroism (*yellow* for rays vibrating parallel to the long axis, and *green* to *colourless* for rays vibrating at right angles to this axis). In these characters and also in crystalline form this mineral agreed with epidote to which it was referred by the author. He considers, however, that no distinction can be drawn between the zoisite-bearing and epidote-bearing saussurites. The plagioclase associated with the zoisite and epidote was determined in one or two cases to be albite. Having established the fact that the saussurites investigated by him were mixtures of zoisite or epidote and felspar, CATHREIN proceeded to calculate the relative proportions of the different constituents from the bulk analyses of certain saussurites, taking TSCHERMAK's formulæas the basis of his calculation. The following case of a saussurite occurring as a constituent of gabbro in the valley of the Wildshönau (Tyrol), will indicate the general nature of his results.

Orthoclase	8·0
Albite	41·0
Anorthite	1·7
Epidote	7·6
Zoisite	41·7
	100·0

(1) Über Saussurit. Z.K., Band VII., 1883, p. 234.

	I.	II.
SiO_2	50·49	53·05
Al_2O_3	25·27	24·24
Fe_2O_3	3·36 ..	3·37
CaO	11·07	12·17
MgO	2·70	—
Na_2O ...	4·93 . ..	4·86
K_2O	1·30	1·35
H_2O	2·11	0·96
	101·23	100·00

I. Bulk analysis of the saussurite.

II. Chemical composition corresponding to the above mineralogical composition.

Microscopic examination showed that the substance contained chlorite, actinolite and calcite in addition to zoisite, epidote and felspar. The difference between the observed and calculated results may therefore be accounted for by the presence of accessory constituents. The principal conclusions of the author may be summed up as follows:—

(1) The so-called saussurite is not an independent mineral, but a mixture of plagioclase (more rarely orthoclase) with zoisite. Actinolite, chlorite and other minerals occur as accessory constituents.

(2) The chemical composition of the saussurite mostly resembles that of the soda-lime felspars. It is, however, poorer in silica, richer in lime, and possesses a higher specific gravity.

(3) Saussurite is a product of the metamorphosis of the felspar through interchange of silica and alkalies with lime, iron and water.

(4) The epidotisation of the felspar is an alteration process which stands in the closest relation with the formation of saussurite (zoisitisation), and differs only in the fact that more iron is taken up.

An important question, not considered by Cathrein, arises directly out of his work. Is the albite an original or secondary felspar? The saussurite, it must be remembered, is a constituent of gabbro. Now, so far as we know, the original felspars of gabbro invariably belong to the labradorite-anorthite series. It is, to say the least, in the highest degree improbable that albite can arise on a large scale as a direct product of the consolidation of a basic magma. This consideration alone points, therefore, to the conclusion that the albite, like the zoisite with which it is associated, is a secondary product. This conclusion is confirmed when we remember that the zoisite and albite, taken together, have practically the composition of a basic felspar, and that the formation of albite, as a secondary product, in connection with the metamorphosis of labradorite, has been established by Lossen in the case of

the Hartz diabases. The subject here referred to at considerable length will be seen to be one of great importance when we have to discuss the origin of hornblende-schists.

It must not be supposed that all saussurites possess the composition and structure of those which have especially engaged the attention of CATHREIN. KLOOS[1] has described the gradual passage of a perfectly fresh violet labradorite ($Ab_1 An_2$) into a milk-white opaque mass in the case of a gabbro occurring at Ehrsberg, in the southern part of the Black Forest.

Examined under the microscope the white mass was seen to consist of a striated felspar and a mineral which occurred in irregularly bounded grains without a trace of cleavage. In thin sections these grains gave bright tints under crossed nicols. The felspar of the opaque white mass was found to be an albite having the composition $Ab_{10} An_1$ and the indefinite minerals proved to be a lime-zeolite of the scolecite type. The specific gravity of the mixture was found to be 2·598.

The secondary felspar was determined by chemical analysis and by optical methods, so that no question can arise as to the accuracy of the result. If we compare the work of KLOOS with that of CATHREIN we observe that the principal difference lies in the fact that scolecite takes the place of zoisite, and that the resulting mixture has consequently a lower specific gravity.

Dr. RFUSCH has described the microscopic structure of the saussurite of a rock from the neighbourhood of Drontheim in Norway.[2] It consists of an aggregate of small columnar crystals or rounded grains of epidote. Plagioclase is quite subordinate to the epidote. The epidote is either perfectly colourless or a pale yellowish green. The characteristic pleochroism can only be recognised in thick sections. The refraction and double refraction are both strong and the basal cleavage is well marked. The extinction referred to this cleavage varies from 0 to 28°. One interesting feature in this epidote is the almost constant presence of twinning, parallel to the orthopinacoid (100). This twinning can only be recognised when the grains are near the position of extinction, in consequence of the fact that the *a*-axis of elasticity makes a very small angle (less than 3°) with the vertical axis of the crystal.

The modifications which the felspars of basic igneous rocks undergo when subjected to mechanical stresses have been studied by several observers, and especially by WERWEKE, LOSSEN and LEHMANN. The felspars of many rocks of the gabbro-family are often seen to be in a state of strain. This is proved by a curvature in the twin lamellæ, and by the fact that the extinction under crossed nicols is not sharp and definite. Dark shadows corresponding to the radii of curvature sweep across the sections as the stage is rotated. When the limit of elasticity has been exceeded the crystal is fractured, and in this case it frequently happens that the twin lamellæ terminate abruptly at the cracks, or run out from them only for a short distance into the crystal-substance. These facts, which have been described and figured by WERWEKE[3]

(1) N.J. Beilage. Band III., 1884, p. 31.

(2) N.J. 1883. Band II., p. 179.

(3) N.J. 1883. Band II., p. 97.

and LEHMANN [1] evidently point to the conclusion that the twin lamellation is at any rate in part a secondary structure. Professor JUDD has argued in favour of the secondary origin of the lamellation in the felspars of the Tertiary gabbros of the West of Scotland. [2] LOSSEN has studied the metamorphic phenomena exhibited by the diabases (dolerites) of the Hartz in great detail and with the most important results, so far as the subject now under discussion is concerned. The granular diabase of this region is a plagioclase-augite rock with ophitic structure—an ophitic dolerite as we should term it. In the district where regional metamorphism has operated with the greatest intensity (S.E. Hartz), the original lath-shaped plagioclase, proved by O. SCHILLING to be a typical labradorite ($Ab_1 An_2$), may often be seen to pass into an aggregate of colourless and for the most part simple (untwinned) grains. This mosaic-like aggregate (albite-mosaic of LOSSEN) in the rock, is sometimes seen to be continuous with a corresponding aggregate which occurs in the form of veins, and in which the grains are sufficiently large to be examined by optical and chemical methods. In such cases they have been found to be albite, and the general conclusion has been reached that this felspar is constantly formed in connection with the metamorphosis of labradorite. That the plagioclase-mosaic is really a secondary formation and not a product of the consolidation of the igneous magma is proved by the fact that it is entirely absent from the normal ophitic dolerites of the Hartz and all other districts, and occurs only in regions which give independent evidence of having been profoundly affected by metamorphic agencies. Epidote and calcite are frequently found associated with the secondary felspar-mosaic, and the original lime of the labradorite is thus accounted for. The individual grains of the aggregates are as a rule perfectly colourless and devoid of twinning. Hence a great difficulty arises in distinguishing between quartz and felspar, as both minerals agree approximately so far as refraction and double-refraction are concerned. When the grains are sufficiently large convergent light may be used, and their biaxial or uniaxial character determined.

If then we combine the researches of LOSSEN, KLOOS and CATHREIN we seem justified in concluding that a basic felspar may be replaced by albite and epidote, zoisite or a zeolite of the scolecite type. It seems also probable that minerals of the scapolite group may arise in consequence of the metamorphism of basic plagioclase. We are ignorant at present as to the precise conditions under which the different kinds of replacement may be effected, but the mosaic structure is certainly often connected with regional metamorphism.

We have now to consider British illustrations of the phenomena above referred to. The gradual passage of glassy labradorite into opaque white saussurite is well illustrated in many of the Lizard gabbros. The commencement of the change is indicated by the development of chalky-white spots in the glassy felspar substance. These increase in abundance until all traces of the original felspar have disappeared. Great difficulty is experienced when

(1) Die Entstehung der altkystallinischen Schiefergesteine, p. 196, and Taf. C. fig. 4.
(2) Q.J.G.S. Vol. XLI., p. 366.

we attempt to determine the precise nature of the white spots. They are often almost opaque in thin section, and never show any definite form or cleavages. In some cases they exhibit a certain amount of transparency, and are then seen to be brown in colour and to possess moderately strong double refraction. Professor PUMPELLY describes the occurrence of similar spots in the felspars of a diabase from Eagle river, and refers them to prehnite.[1] Whatever the mineral forming these spots may be, it is a constant or nearly constant feature in the Lizard saussurite, which thus does not answer to the description of saussurite as given by CATHREIN. The other recognisable constituents in the Lizard saussurite are felspar, epidote, tremolite and actinolite. There is also very often a minutely granular substance giving aggregate polarisation. Different specimens of saussurite differ considerably in the relative proportions of the different constituents. Indeed it must be remembered that the term saussurite has no precise signification. It is merely employed to designate the dense light-coloured aggregates which arise in connection with the alteration of a basic felspar. Mr. HUDDLESTON gives the following analysis of a mass of saussurite from a coarse grained gabbro which occurs near Caerleon Cove.[2]—

SiO_2	45·70
Al_2O_3	23·00
Fe_2O_3	·50
CaO	19·30
MgO	4·75
Alkalies, &c., (diff.)	1·95
Ig.	4·80
	100·00

He remarks "that the compound has more affinity, as regards its percentage of silica, with anorthite than with labradorite; but the presence of so much magnesia, and its poverty in alkali must lead us to regard it as a mixture rather then as a mineral species worthy to be classed with the felspars." The magnesia in the above analysis is accounted for by a pale coloured hornblende which was recognised by Professor BONNEY in the material submitted to Mr. HUDDLESTON for analysis. If we compare the analysis of Lizard saussurite with the analyses of various saussurites by DAMOUR, HUNT, BOULANGER and others [3] we are struck by the fact that it contains less silica and alkali, and more water than the average. The original felspar was, as Mr. HUDDLESTON suggests, probably more allied to anorthite than to labradorite. The presence of over 4 per cent. of water accords with the view that the doubtful mineral which was referred to in describing the microscopic structure of the substance is a lime-zeolite.

Associated with the exposure of actinolitic gabbro in Sangomore Bay,

(1) Proc. Amer. Acad. 1878, p. 272.
(2) Q.J.G.S., vol. XXXIII., 1877, p. 927.
(3) See RAMMELSBERG. Handbuch der Mineralchemie, p. 566.

near Durness, in Sutherlandshire, is a mass of rock composed of a pinkish saussuritic looking substance and hornblende. On examining a fractured surface of the supposed saussurite, glistening cleavage surfaces may be detected here and there. Under the microscope it is seen to consist of colourless prismatic microlites and a water-clear groundmass which splits up under crossed nicols into large, irregular, untwinned grains. The microlites give straight extinction, and are traversed by cross fractures at irregular intervals. They possess strong refraction and weak double refraction ; or, in other words, their relief is strongly marked, but they give under crossed nicols only the neutral tints of the first order. In all these characters they agree with zoisite, to which mineral we may accordingly refer them. The colourless groundmass possesses the refraction and double refraction of felspar. As already mentioned, distinct cleavage surfaces may occasionally be seen in the saussuritic aggregate. A fragment broken off from one of these and tested by SZABO's method gave the flame colouration and fusibility characteristic of albite. We may therefore conclude that we have here a saussurite similar to that described by CATHREIN ; that is a mixture of zoisite and albite, with a variable quantity of hornblende occurring as an accessory constituent.

The rocks of Sangomore Bay have been profoundly affected by regional (pressure) metamorphism, and it seems probable, therefore, that the zoisite and albite have been developed, in connection with this metamorphism, from the basic felspar of a gabbro.

The Scourie dykes[1] furnish us with interesting illustrations of the modification to which the plagioclase of a basic eruptive rock is subjected under the influence of powerful mechanical stresses. The original felspars give lath-shaped sections. If a series of microscopic slides illustrating the passage of the massive plagioclose-augite rock into a crystalline schist be examined under the microscope, it will be seen that the change is accompanied by a molecular re-arrangement of the felspar.

This is proved not only by the fact that the original form and internal structure (twinning) of the felspar is lost, but also by the occurrence of secondary hornblende as inclusions in the felspathic aggregates. The manner in which the molecular re-arrangement of the felspar takes place appears to vary under varying circumstances. Sometimes cloudy crypto- or micro-crystalline aggregates are formed ; at other times the mosaic-like aggregate of colourless grains is produced ; while at others the secondary felspar occurs in the form of large irregular grains. Two features are especially striking in the secondary felspar—the comparative absence of twinning and its wonderful clearness. Where it occurs in detached grains, or even in aggregates, it is often quite impossible to distinguish it from quartz without the use of convergent light. An important question arises as to the nature of the secondary felspar. At one point, where the more southerly dyke has been greatly affected by the deforming forces, a vein of nearly pure felspar substance occurs. The individual grains are large, irregular in form, and devoid of twinning. They have a specific gravity of 2·65, and a composition

(1) TEALL. On the Metamorphosis of Dolerite into Hornblende-Schist. Q.J.G.S., vol. XLI., 1885, p. 133.

which is represented by the following analysis :—

SiO_2	58·16
Al_2O_3	26·66
CaO	5·79
MgO	·65
Na_2O	6·99
K_2O	1·76
	100·01

They belong, therefore, to andesine. As the vein is certainly of secondary origin, and connected with the metamorphosis of the dyke, this makes it highly probable that felspars other than albite may arise as secondary products in metamorphosed basic eruptive rocks.

Monoclinic Pyroxene. The monoclinic pyroxenes are very largely represented in the basic igneous rocks, and, so far as we know at present, they are in every case either the product of crystallization from the molten magma, or the result of the action of the magma on pre-existing crystals (*e.g.*, hornblende). In no case are they known to have been formed in basic igneous rocks by secondary processes acting after consolidation. The monoclinic pyroxenes vary considerably in chemical composition, and, notwithstanding the very large amount of information which has been accumulated,[1] we are still very far from a complete knowledge of the molecular composition of the group. According to the view of TSCHERMAK the pyroxenes (except Wollastonite), are isomorphous mixtures of the following molecular groups:—Ca Mg Si_2O_6 (diopside-molecule), Ca Fe Si_2O_6 (Hedenbergite-molecule), Mg Al_2 Si O_6, Mg Fe_2 Si O_6, Fe Al_2 Si O_6 and Na Fe Si_2 O_6 (akmite-molecule). DÖLTER and others have shown, however, that other groups must be added to the above in order to explain the composition of all the known pyroxenes.

It is customary to divide the monoclinic pyroxenes into two groups, depending on the presence or absence of considerable quantities of elements in the sesquioxide condition (alumina and ferric oxide). To the first division belong the varieties designated by the terms diopside, salite, malacolite and diallage; to the second, the common augites. There is, however, no hard and fast line between the different groups, and many diallages contain five and six per cent. of alumina. An important question arises as to the classificatory value of diallage. The distinctive character of this variety is a lamination, often due to the presence of inclusions, parallel or approximately parallel to the orthopinacoid (100). As there is good reason to believe that this lamination is of secondary origin,[2] and as it is certain that it may be

(1) See DÖLTER. Über die Constitution der Pyroxengruppe. T.M.M., Neue Folge, vol. II., 1879. p. 193.

(2) BISCHOF held the view that diallage is merely altered augite (see Chemical and Physical Geology, English Edition, vol. II., p 334). It was confirmed by STRENG (Gabbro des Harzes. N.J., 1862, 933), who pointed out that one and the same individual could be augite in one part and diallage in another.

present in one part of a crystal and absent from another part of the same crystal, it is difficult to regard it as of much significance. The following is a list of analyses of monoclinic pyroxenes occurring in British rocks of the group now under consideration.

	I.	II.	III.	IV.	V.
SiO_2	50·537	51·362	50·80	53·046	51·936
Al_2O_3	3·348	1·662	3·00	4·816	1·322
Fe_2O_3	1·338	8·968	9·61	11·389	13.900
FeO	4·423				
MnO	0·230	0·332	1·08	0·078	0·250
CaO	21·419	20·837	19·35	19·808	19.363
MgO	17·050	16·471	15·06	11·576	13·850
K_2O	0·252	—	—	—	—
Na_2O	0·530	—	0·66	—	—
H_2O	0·706	0·540	0·60	0·626	0·200
	99·833	100·172	100·16	101·339	100·821

	VI.	VII.	VIII.	IX.
SiO_2	51·30	49·268	50·10	48·41
Al_2O_3	0·76	0·222	6·77	4·05
Fe_2O_3	13·92	14·080	6·90	2·36
FeO				15·08
MnO	0·25	0·381	—	·37
CaO	20·15	20·256	17·46	15·98
MgO	14·85	14·812	17·47	12·14
K_2O		—		—
Na_2O		—		—
H_2O	0·21	0·719	1·30	1·19
	101·44	99·738	100·00	99·58

I. Green diopside. Gabbro. Halival, Isle of Rum. Dr. Heddle, Trans. Roy. Soc., Edin., vol. XXVIII., 1879, p. 478.

II. Green diallagic augite. Sp. Gr. 3·329. Gabbro. Hart O'Corry, Skye. Dr. Heddle, *loc. cit.*, p. 479.

III. Augite. Lock Scavaig, Skye. Dr. Houghton. Dublin Quart. Jour. Geol. Soc., vol. V., 1865, p. 95.

IV. Greyish green diallagic augite. Corry na Creech, Cuchullin Hills, Skye. Sp. Gr. 3·329. Dr. Heddle, *loc. cit.* p. 479.

V. Diallagic augite. Drum-na-Rabn, Cuchullin Hills, Skye. Dr. Heddle, *loc. cit.* p. 419. Sp. Gr. 3·335. This augite contained also ·380 of TiO_2.

VI. Diallage, Skye. Vom Rath: see Rammelsberg, Handbuch der Mineralchemie, 1860, p. 465.

VII. Dark green diallagic augite. Loch Scavaig, Skye. Sp. Gr. 3·321. Dr. Heddle, *loc. cit.*

VIII. Diallage from gabbro. Caerleon Cove, the Lizard, Cornwall. Mr. Huddleston. Q.J.G.S., Vol. XXXIII., p. 927.

IX. Augite from the Whin Sill, (Enstatite-dolerite). Teall, Q.J.G.S., Vol. XL., 1884, p. 648.

It will be observed that most of the British rock-forming augites, of which analyses have been made, come from the Tertiary gabbros of the West of Scotland, and that they belong to the division which is poor in alumina. The augite of the Whin Sill corresponds very closely to the following formula—

$$\left.\begin{array}{l} 14\ Ca\ Fe\ Si_2O_6 \\ 5\ Ca\ Mg\ Si_2O_6 \\ 6\ Mg\ Mg\ Si_2O_6 \\ 3\ Mg\ Al_2\ Si\ O_6 \\ 1\ Mg\ Fe_2\ Si\ O_6 \end{array}\right\}$$

This mineral is remarkable for the large amount of iron, existing presumably in a silicate of the Hedenbergite type, and for the excess of magnesia over that required to combine with the remaining lime and the sesquioxide bases. The excess implies the existence of the silicate $Mg\ SiO_3$, written in the formula as $Mg\ Mg\ Si_2O_6$ for the sake of symmetry. Whatever theory we adopt as to the constitution of the pyroxenes, we seem driven to the conclusion that this silicate, known to us as the rhombic mineral enstatite, exists in a monoclinic augite. One point is certain, viz. that the substance analysed did not consist of a visible mixture of rhombic and monoclinic pyroxenes.

Augite occurs in the basic eruptive rocks as crystals, irregular crystalline masses, granules, and granular aggregates. When it occurs as crystals the common forms are the orthopinacoid (100), the prism (110), the clinopinacoid (010) and the positive hemipyramid ($11\bar{1}$).

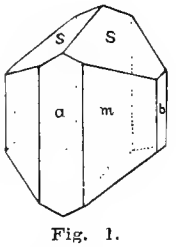


Fig. 1.

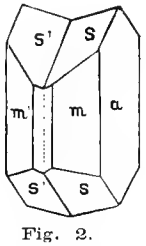


Fig. 2.

Fig. 1. Augite crystal. – a = (100), b = (010), m = (110), s = ($1\bar{1}1$).
Fig. 2. A twinned crystal of augite.

The larger crystals are usually short in proportion to their width; the smaller crystals are often elongated in the direction of the vertical axis. The prismatic angle is the most important for petrographical purposes. It is about 87°, and does not vary to any considerable extent in the different varieties.

The principal cleavages are parallel to the prismatic faces, and intersect therefore at an angle of 87°. Cross-sections are eight-sided, and the boundaries are determined by the faces in the prismatic zone, (100), (010) and (110). In some augites the prismatic faces and in others the pinacoidal faces are the best developed; the former can, as a rule, be readily distinguished from the latter by the parallel cleavage cracks. The most common type of twinning is the one in which the orthopinacoid (100) is both twin-plane and face of composition. Sometimes the twinning is repeated several times in the same individual, but this feature is comparatively rare.

The double refraction of augite is strong, so that thin sections give, on the average, high interference tints. It is stronger than that of the rhombic pyroxenes, but not so strong as that of olivine. The mean axis of elasticity always coincides with the ortho-diagonal ($b=\beta$), so that the optic axes lie in the plane of symmetry. The acute bisectrix is positive, and in the normal augites (not akmite) always makes a considerable though variable angle with the vertical axis. This angle ($c:\gamma$) is an important characteristic for the minerals of this group. It is the maximum extinction in sections out of the zone of the vertical axis; that is, in sections in which the two sets of cleavage cracks are parallel to each other. As already stated it varies in different augites and is no doubt related to the chemical composition. All that can be said, however, at present is that it is somewhat less in those augites which are poor in iron and alumina than it is in those which are rich in these substances. In the former it varies between 36° and 40° and in the latter between 41° and 54°. The optic axial angle also varies considerably in different augites, but as this element cannot be determined in ordinary rock sections, and with the simple appliances of an ordinary petrographical microscope, it possesses less importance from our point of view than the angle $c:\gamma$. Now in observing augite-sections under the microscope the zone 100 : 001 becomes of considerable importance because sections out of this zone are at right angles to the optic axial plane, and therefore show when viewed in convergent polarised light different portions of the interference figure in the most favourable position for examination. Such sections may be easily distinguished by the fact that the extinction position bisects the angle formed by the cleavage cracks, and lies parallel to the cleavage cracks when these are parallel to each other. In the latter case the section must not only be out of the zone 100 : 001, but can only be cut in one direction in this zone, namely parallel to 100. If examined in convergent light, such a section will show an optic axis somewhat oblique to the axis of the microscope. This is often a valuable means of discriminating between rhombic and monoclinic pyroxenes. Longitudinal sections giving straight extinction *must*, if the crystal be augite, show an optic axis, or at any rate an axial shadow; whereas, if the crystal be a rhombic pyroxene, all longitudinal sections will give straight extinction, and in none of them will a single optic axis be visible. Cross sections of an augite prism also show an optic axis somewhat oblique to the field of view, whereas the corresponding sections of a rhombic pyroxene show a positive bisectrix.

M. Thoulet has given tables [1] which show the relation between the angle made by the two sets of cleavage cracks and the direction in which the section is cut; for sections out of the three principal zones, and these tables are often of considerable use in determining the orientation of any particular section.[2]

The colour of the monoclinic pyroxenes varies considerably in different individuals, and sometimes in different portions of the same individual. Some varieties are colourless in thin section, others are brown, yellowish-brown or brownish-violet, and others a pale green. Knop [3] has recently shown that certain reddish-brown or violet-brown augites contain several per cent. of titanic acid. The augites of the basic eruptive rocks are not as a rule markedly pleochroic. Some of the deeply coloured varieties do, however, show a perceptible pleochroism of the kind referred to in describing the Inchcolm picrite. The hour-glass structure already mentioned as occurring in the picrites is occasionally found in the normal plagioclase-augite rocks. Zonal structure due to a variation in the colour of successive layers is occasionally seen in the porphyritic augites of certain dolerites and basalts.

Augites showing good external form are comparatively rare in British rocks of basic composition. They occur, however, as porphyritic elements in dolerites of the Lion's Haunch (Edinburgh) type, and as constituents of the main mass of the rock in those of the Rowley Rag type. The porphyritic augites frequently contain portions of the groundmass, magnetite and sometimes olivine as inclusions. As a general rule the augite of the coarsely crystalline (gabbros) and medium grained rocks (dolerites) occur as large grains or irregular masses (ophitic), and those of the finer grained rocks (basalts) as granules and granular aggregates. We sometimes find in the basalts minute well-formed augite crystals lying in a groundmass of felspar. (see fig. 2, plate XXIV.) This is a common feature in the Tertiary felspar-basalts of the continent, but it is rare or absent from the corresponding rocks in this country. With us, on the other hand, it is found amongst the carboniferous basalts of the Midland Valley of Scotland and the neighbourhood of Limerick, in Ireland. Microlites of augite are sometimes present in rocks with a considerable amount of glassy base. If we compare the rocks of the tertiary with those of the palæozoic periods in the British Isles, it is interesting to notice that the augites with well marked crystalline form appear to be much more abundant in the latter. It is amongst the carboniferous rocks of the Midland Valley of Scotland and the neighbourhood of Limerick, in Ireland, that we find the most perfect crystals of augite. Ophitic augites are equally abundant in the palæozoic and tertiary rocks.

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(1) See Fouqué and Lévy. Minéralogie Micrographique; also Hussak Einleiteng zum bestimmen der gesteinbildenden Mineralien, p. 64.

(2) Thus, taking the zone 100 : 001, the angle varies from 0° to 87°. By observing the angle and referring to the table, it is possible to determine the inclination of the section to the vertical axis of the crystal. If such a section should be cut at right angles to an optic axis, then the angle which this axis makes with the vertical axis is known, and by combining this observation with the observation of the maximum extinction in the zone of the vertical axis it is possible to obtain an approximation to the optic axial angle.

(3) Z.K. 1885, p. 58.

The variety of augite known as diallage is especially characteristic of the gabbros. Its distinguishing feature is the presence of a lamination parallel to the orthopinacoid. This lamination is frequently accompanied by the presence of minute brownish plates, which lie parallel with the same plane and give a bronzy lustre to the cleavage surfaces. In the variety known as pseudo-hypersthene similar inclusions occur along more than one set of parallel planes (see *ante*, p. 29.)

When affected by surface agencies the augite of basic eruptive rocks often passes into ill-defined fibrous or granular substances of a greyish colour. Another common alteration product is chlorite. This occurs in the form of scaly or fibrous aggregates, which give under crossed nicols a peculiar deep blue shimmering light. It is very common amongst the older plagioclase-augite rocks, and is, indeed, the only mineralogical feature available for distinguishing these rocks from the tertiary dolerites; and even this feature is not constant. Calcite and minute epidote granules are often found associated with chlorite. The non-aluminous augites may give rise to serpentine.

The effects of the intrusion of granite upon the augite of basic igneous rocks has been described by Mr. Allport,[1] and his results have been shown to possess a general significance by the work of Lossen[2] in the Hartz and Michel-Lévy[3] in the Mâconnais. The augite passes into uralitic and actinolitic hornblende. The term *uralitic* is applied when a crystal or grain of augite is converted into an aggregate of hornblende-fibres without the destruction of the original form of the crystal or grain; the term *actinolitic*, on the other hand, implies that the original form has been more or less destroyed, and the fibres individualized as distinct needles of actinolite. Speaking of the hornblende developed by contact metamorphism, Mr. Allport says: "Like all hornblende it exhibits colours in polarized light and is dichroic: but the crystals differ in character from those occurring in diorites and other igneous rocks; nor are they the same as those forming the true hornblende-schist of the Lizard District for example; they have often the character of actinolite, and are frequently aggregated in radiating groups composed of flat blades of a bluish-green colour, and not very translucent; occasionally, however, there are crystals quite similar to those in ordinary hornblende-schist." That the conditions under which the metamorphism of the rock was affected admitted of a considerable amount of movement amongst the chemical constituents without, at the same time, producing anything like fusion, is proved by the fact that it is often traversed by cracks, now filled with actinolite, quartz and probably in some cases a colourless secondary felspar. The last sentence quoted from Mr. Allport's paper is important because it shows that compact hornblende[4] may arise in

(1) On the metamorphic rocks surrounding the Land's End mass of granite. Q.J.G.S., vol. XXXII., 1876, p. 407.

(2) Jahr. d. k. preuss. geol. Landesanstalt für 1883 und 1884.

(3) B.S.G., Se. III., Tome XI., p. 273.

(4) By "compact hornblende" is meant hornblende which is homogeneous; that is, neither fibrous nor actinolitic.

connection with contact metamorphism as well as the more common uralitic and actinolitic modifications.

Pressure or regional metamorphism also changes augite to hornblende. The development of hornblende at the expense of the augite or diallage of the basic igneous rocks, in regions not affected by contact metamorphism, has been described by a number of observers [1]; and may now be regarded as one of the most definitely established facts in petrographical science. The secondary hornblende may occur in the compact, uralitic or actinolitic conditions. The compact hornblende may be either brown, green, or colourless. Green varieties are perhaps the most common, and in the metamorphosed gabbros these frequently assume the bright grass-green tint which characterises smaragdite. The compact uralitic and actinolitic varieties may occur together; but more frequently the compact variety is not found in association with the other two. The gradual replacement of diallage by irregular grains of compact hornblende is well seen in some of the Lizard gabbros. The change appears to commence at the margins and to extend inwards until all trace of the original mineral has disappeared. Large crystals of diallage, measuring an inch or more in diameter, may be converted into an aggregate of small hornblende grains without any uniform orientation. This change is often accompanied by a change of the felspar to saussurite, and by a plastic deformation of the rock-mass which results in the development of the "flaser," "augen," and schistose structures to be subsequently described. We have no information as to the relation between the secondary hornblende and the original diallage in these rocks so far as chemical composition is concerned. STRENG, however, has analyzed the diallage and hornblende occurring under similar conditions in the Hartz gabbros.

	I.	II.	III.	IV.	V.
SiO_2	52·84	45·73	52·88	52·34	51·70
TiO_2	0·22	—	—	—	0·57
Al_2O_3	4·56	5·60	2·82	3·05	5·41
Cr_2O_3	0·09	—	—	—	0·08
Fe_2O_3	1·84	12·18	8·40	0·00	0·00
FeO	9·41	8·00		8·84	6·67
CaO	13·16	8·86	17·40	19·18	19·68
MgO	16·05	12·55	17·68	15·58	15·08
$Na_2O(K_2O)$	0·39	0·55	—	—	0·37
H_2O	3·29	4·68	1·06	0·66	0·82
	101·85	98·15	100·24	99·65	100·38
Sp. Gr.	3·00	3·01	—	3·25	3·22

(1) STRENG, Gabbro des Harzes, N.J., 1862, p. 933; BONNEY, on the Serpentine and associated rocks of the Lizard District, Q.J.G.S., vol. XXXIII. 1877, p. 884; LOSSEN, Studien an metamorphischen Eruptiv- und Sedimentgesteinen. Jahr. d. Preuss. geologischen Landesanstalt für 1883 and 1884 (where references to previous papers on the same subject dating as far back as 1869 will be found; LEHMANN, Die Entstehung der altkystallinischen Schiefergesteine. Bonn, 1884, p. 190; HATCH, Über den Gabbro aus der Wildshönau in Tirol, 1885, p. 75; G. H. WILLIAMS. The Gabbros and associated Hornblende rocks occurring in the neighbourhood of Baltimore, Bull, U.S., Geol. Survey, No. 28, 1886.

I. Very coarse grained diallage from Baste.

II. Coarse grained diallage (altered) from same locality.

III. Diallage from Baste. Analysis by Köhler, quoted by Streng.

IV. Augite from Gabbro, Baste. This mineral was surrounded by hornblende.

V. Augite associated with the diallage of analysis I.

	I.	II.	III.
SiO_2 ...	50·72	52·13	52·11
Al_2O_3 ...	3·38	6·18	4·49
Fe_2O_3 (...	17·48	1·14	0·00
FeO) ...		9·06	10·88
MnO ...	—	0·14	—
CaO ...	13·13	14·32	16·83
MgO ...	11·54	17·30	14·23
H_2O ...	1·12	0·73	0·90
	97·37	101·00	99·44
Sp. Gr.	—	3·13	3·17

I. Hornblende varying from bright green to dark green.

II. Dark chesnut-brown hornblende from a gabbro poor in diallage, Baste.

III. Hornblende associated with the diallage whose composition is given in analysis II. of the preceding list.

The change of diallage to uralitic and actinolitic hornblende may also be observed in some of the Lizard gabbros. In this case the original mineral is replaced by an aggregate of hornblende fibres which lie approximately parallel to each other in the central portions of the mass, but which run out at the margin into a fringe of actinolitic needles. These needles invade the colourless felspar substance with which they are surrounded, as is well shown in fig. 2, plate XVIII. The augite of the dolerites exhibits the same tendency to pass over into hornblende. This is well seen in the case of the Scourie dykes, in the so-called greenstones of Devon and Cornwall,[1] and in the black dykes of the Lizard peninsula.

As already stated, the secondary hornblende may be either brown, green or colourless. The pleochroism of the green varieties is generally as follows:— α=pale greenish yellow, β=dark or pale yellowish green, γ=rich deep green or bluish green.

In considering the distribution of augite and hornblende in the basic

(1) See papers by Mr. J. A. Phillips on the so-called greenstones of Cornwall, Q.J.G.S., vols. XXXII and XXXIV.

igneous rocks nothing strikes one so much as the evident instability of the former mineral at low temperatures, as shown by its tendency to pass over into the latter. An important question arises as to what extent the change is dependent on the agencies generally included under the terms contact and regional metamorphism. It would be a mistake to suppose that such agencies are absolutely necessary to effect the change,[1] at the same time we must bear in mind the important fact that those areas where this change is most pronounced are precisely those that have been most affected by contact and regional metamorphism. This subject will be again referred to when the rocks are described.

Rhombic Pyroxene. The rhombic pyroxenes—enstatite, bronzite, and hypersthene, (see *ante*, page 87)—are not known to play a very important part in the British rocks of basic composition. They occur, however, in the gabbros of the West of Scotland, and in certain finer grained rocks of the doleritic type; as, for example, in certain portions of the Whin Sill and in allied rocks from Ratho, near Edinburgh, and Kilsyth in the Campsie Fells. Professor Judd calls attention to the existence of hypersthene in a dolerite which forms a subordinate dyke in the great serpentine dyke of Forfarshire.[2] In the rocks of the gabbro-family the rhombic pyroxenes usually occur in grains without definite external form; in the dolerites they usually show a more perfect form. It is not, however, until we come to the rocks of intermediate composition, the andesites and porphyrites, that we find the crystals perfectly developed.

The prismatic angle of the rhombic pyroxenes agrees very closely with that of augite. In the unaltered crystals or grains the two principal cleavages are those parallel to the prismatic faces; so that, in this respect, there is no marked difference between the two groups of the pyroxenes. The characters of most use in discriminating between the two groups have been already referred to and need not therefore be recapitulated. When crystalline form is developed, the crystals are usually elongated in the direction of the vertical axis. The common forms in the prismatic zone are the orthopinacoid (100), the brachypinacoid (010), and the prism (110). The prismatic faces are, as a rule, less developed than the pinacoids. The crystals are sometimes seen to be terminated by two faces (brachydomes) meeting at an obtuse angle. As the crystals are usually placed for reference the vertical axis corresponds with the least axis of elasticity ($c=\gamma$), and the mean axis of elasticity with the macro-diagonal ($b=\beta$). The optic axial plane is therefore parallel with the brachy-pinacoid (010). A cross section of the prism of a rhombic pyroxene shows the two sets of cleavage cracks meeting at an angle of about 90°, and gives in convergent light a positive bisectrix. In enstatite and bronzite this is the acute bisectrix; in hypersthene it is the obtuse bisectrix. By alteration the rhombic pyroxenes develope a cleavage or lamination parallel to the brachypinacoid. In the bronzites and hypersthenes of the rocks of the gabbro-family we sometimes

(1) Thus the change to uralite is found in districts where these agencies have not operated.

(2) Q.J.G.S., vol. XLI., 1885, p. 399.

find, as inclusions, the minute tables and rods (see *ante* p. 29) which give the "schiller," so long regarded as characteristic of these minerals.

The occurrence of definite inter-growths of rhombic and monoclinic pyroxenes (see *ante* p. 31) may sometimes be observed. The alteration of the rhombic pyroxenes in the rocks now under consideration is essentially similar to that in the peridotites. A good illustration of the mode of decomposition is seen in fig. 2 plate XIII. Mr. G. H. Williams and Dr. Lehmann have described the conversion of hypersthene into compact hornblende.

Olivine. This mineral plays a most important part in the basic eruptive rocks. It occurs in crystals, grains, and granular aggregates. Well-formed crystals are comparatively rare. When they do occur they give rise to sections which are remarkable for their symmetry. These sections are frequently six-sided, and the two edges which represent the terminal faces meet at an acute angle (see fig. 2, plate X.). The chemical composition of olivine is represented by the formula $(Mg\ Fe)\ SiO_4$, and the principal varieties are due to varying proportions of the two bases. In normal olivine the amount of ferrous oxide is generally less than 16 p.c.; in the variety known as hyalosiderite it rises to 28 p.c. Olivine may be colourless, yellow, or yellowish brown. The depth of colour is an indication of the amount of iron, and generally when the colour is in any way conspicuous the mineral may be referred to hyalosiderite. This is the case with some of the olivines in the dolerites of Rowley Regis and the West of Scotland.

Olivine, from the Summit of Halival, Isle of Rum. (1)

SiO_2	38·006
Al_2O_3	0·286
Fe_2O_3	2·933
FeO	18·703
MnO	0·100
CaO	0·336
MgO	38·000
H_2O	1·587
	99·945
Sp. Gr.	3·327

Olivines rich in iron assume a red or reddish brown colour when heated. In some of the olivines in the dolerite near Portrush the central portions are colourless, or nearly so, while the marginal portions are a deep reddish brown. This is probably due to an action of the magma on already formed crystals. The refraction of olivines is very high, and consequently the surface usually appears rough under the microscope. The double refraction is strong, and tints of the third order are frequently seen, even in very thin sections. Olivine in thin section is readily acted upon by hot hydrochloric acid, and this

(1) Dr Heddle. Min. Mag. vol. V. (1884), p. 16.

is sometimes a useful test in discriminating between this mineral and pyroxene. The olivine of the gabbros is usually in the form of grains and granular aggregates; that of the dolerites and basalts may occur as grains, granular aggregates, or crystals. In the plutonic rocks the mineral is frequently traversed by cracks, along which magnetite has separated out and sometimes minute opaque stellate and dendritic inclusions (see *ante* p. 30) occur in the substance of the crystal. Professor JUDD has called attention to the fact that the olivines of the gabbros are frequently rendered opaque by this separation of secondary magnetite. In the consolidation of the basic magma olivine is always one of the first minerals to form. It precedes in date the pyroxenes and the felspars, and often occurs as inclusions in these minerals. The alteration of olivine to serpentine has already been described in treating of the peridotites (see *ante* p. 85). The occurrence of certain minerals (tremolite, actinolite, anthophyllite and pyroxene), in the form of zones round the olivines of certain gabbros and allied rocks has been described by TÖRNEBOHM,[1] BECKE,[2] ADAMS,[3] and WILLIAMS.[4] It is regarded by ROSENBUSCH as a result of pressure metamorphism, and by WILLIAMS as an original structure, dating from the time of the consolidation of the magma. Professor BONNEY has remarked on the general absence of olivine from the hornblendic gabbros of the Lizard, and suggested that this absence may be due to the fact that olivine as well as diallage may have contributed to the formation of hornblende.

Hornblende. This mineral occurs as an original and also as a secondary product in basic eruptive rocks. Original hornblende is comparatively rare. It occurs as crystals and crystal fragments or as more or less rounded grains which have lost their crystalline outlines by the action of the magma on previously formed crystals. The forms in the zone of the vertical axis are those of the prism (110), the clinopinacoid (010), and less frequently the orthopinacoid (100). The crystals are usually elongated in the direction of the vertical axis and terminated by clinodomes (011), or by a combination of a hemipyramid ($\bar{1}11$) and the basal plane (001). The prismatic angle for all hornblendes is approximately 124° 30′. The original hornblende of the basic rocks is a deep brown colour, similar to that already described in speaking of the picrites (see *ante* p. 91). The pleochroism and absorption are also similar. The prismatic cleavages are always well developed and furnish, therefore, a most important diagnostic character in the absence of definite form. In cross sections of the prism the angles made by the two sets of cleavage cracks are 124° and 56°. Longitudinal sections show parallel cleavage cracks and give extinctions varying from 0°, when the section is parallel to the orthopinacoid (100) to 20° or less, when the section is parallel to the clinopinacoid (010). Sections out of the zone 100 : 001 are distinguished by the fact that the extinction position bisects the angles formed by the cleavage cracks; and, as the optic axial plane is the plane of symmetry,

(1) N.J., 1877, p. 383.
(2) T.M.M., 1882, vol. IV pp. 330, 355, and 450.
(3) American Naturalist, 1885, p. 1087.
(4) A.J.S., 1886, p 35.

such sections show in convergent light the bisectrices and the optic axes. The crystals are frequently twinned in such a way that the orthopinacoid (100) is both twin-plane and face of composition; and not seldom several lamellæ are seen to be interposed between the two principal portions. We have no analyses of the hornblende of the British basic eruptive rocks. It occurs in a dolerite from Necropolis Hill, Glasgow (see fig. 1, plate XIII.), in certain allied rocks from the neighbourhood of Plymouth, and in the basic diorites of the Warwickshire type. (1) In the last mentioned rocks it is sometimes found as ophitic plates and sometimes as well formed crystals. Brown hornblende and augite are sometimes found intergrown with each other in such a way that the plane of symmetry and vertical axis are common to both minerals. This may be observed in the Whin Sill and in a "greenstone" from St. Minver, in Cornwall. The relations are similar to those described in the case of the Inchcolm picrite. The development of secondary hornblende as a consequence of the alteration of pyroxene has already been referred to. Uralite, actinolite, and "compact" hornblende may be produced in this way, and the latter variety may be either brown, green, or colourless. Brown hornblende of a secondary character appears however to be comparatively rare.

Magnetite and Ilmenite. Oxides of iron with a variable amount of titanic acid are almost constantly found in basic eruptive rocks. They occur as crystals, skeletons, and grains. In thin sections they are perfectly opaque. Magnetite crystallises in the form of the octahedron, and the crystals are often very minute. Sections may be square, triangular, or hexagonal. Twins according to the spinelle-type, that is with an octahedral face as the twinning plane, are common, and sections of such twins taken at right angles to the twinning plane are often somewhat lath-shaped in section with a re-entering angle at one end and a projecting angle at the other. The lath-shaped form is due to a flattening in the direction of the twinning-axis. In rocks which contain a glassy base minute crystals and grains of magnetite are often seen to be arranged in straight lines so as to form rods, which in turn build up skeleton crystals. An exquisite illustration of this is seen in a basalt from North Berwick (Scotland) figured by Vogelsang. (2) Magnetite may be entirely removed from a thin section by treatment with hot hydrochloric acid, and this is sometimes a useful means of distinguishing it from ilmenite; the latter mineral being much less readily affected. The mineral may be easily extracted from the powder of the rock with a magnetic needle. The composition of pure magnetite is represented by the formula $FeO\ Fe_2O_3$; that of the basic igneous rocks usually contains a considerable amount of titanic acid. Magnetites which are poor in titanic acid yield hydrated ferric oxide when subjected to alteration by surface agencies; those rich in titanic acid decompose in the same way as ilmenite.

Ilmenite occurs in irregular masses without definite crystallographic boundaries and as hexagonal tables. Beautiful examples of the latter mode of occurrence may sometimes be observed in the dolerite of Rowley

(1) See Allport. Q.J.G.S., XXXV., 1879, p. 637.

(2) Die Krystalliten, fig. 1, Taf. XIII.

Regis. Not seldom plates of ilmenite are seen to be arranged in parallel rows intersecting each other at angles of 60°. The theoretical composition of ilmenite is represented by the formula $FeTiO_3$, but chemical analyses usually show a certain amount of Fe_2O_3 and it is probable that a perfect series exists between Fe_2O_3 and $FeTiO_3$. Ilmenite and hematite are not attracted by the magnet. The common alteration product of ilmenite is a whitish or yellowish substance which was first described by GÜMBEL [1] and named leucoxene. It may be opaque or semi-transparent. In the latter case it shows strong refraction and double refraction. The true character of this alteration product was determined by CATHREIN. [2] He analysed the leucoxene of a rock from the Alpbachthal and found that it possessed the chemical composition of sphene ($CaO\ SiO_2\ TiO_2$). As typical sphene possesses well marked optical characters it seems desirable to retain the term leucoxene for the ill-defined alteration product. The alteration of ilmenite sometimes commences at the margin and proceeds inwards until all trace of the original mineral has disappeared; at other times it proceeds along two sets of parallel planes which appear to intersect each other at angles of 60° and 120°; thus etching out as it were a structure that would otherwise escape notice. NEEF [3] found, on treating a certain section of diabase with hot hydrochloric acid that the opaque iron ore was partially destroyed, a fine net-work, due to two parallel series of lamellæ intergrown so that the angles between them corresponded to the angles of the fundamental rhombohedron remained behind. KUCH [4] obtained precisely similar results in the case of a similar rock from West Africa. Now, as magnetite is much more readily dissolved than ilmenite, this seems to imply that in these cases the original substance was an intergrowth of these two minerals; at any rate it proves that the opaque iron oxide was not homogeneous.

Saussure described under the name of sagenite certain curious reticulated aggregates of rutile (TiO_2) in which the angles of the meshes are 60° and 120°; and CATHREIN infers the existence of such aggregates in the ilmenite which furnished the leucoxene that he analysed. It is an interesting fact that the reticulated structure so frequently developed in the opaque iron oxides of the dolerites (diabases), as for example in certain portions of the Whin Sill, should so closely resemble in character the sagenite-aggregates of Saussure. The occurrence of rutile in sagenite-form in hematite has been described by GYLLING.[5]

When the opaque iron oxides occur in the form of grains and irregular ragged aggregates it is in many cases impossible to determine whether they should be referred to magnetite or ilmenite. The presence of leucoxene as an alteration product is not decisive, as this may arise from the decomposition of a titaniferous magnetite. The author found that the iron ores of the

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(1) Die paläolithischen Eruptivgesteine des Fichtelgebirges. München, 1874, p. 22.
(2) Über Titaneisen, Leukoxen und Titanomorphit. Z.K., 1882, VI., p. 244.
(3) Z.D.G.G. Vol. XXXIV., p. 470.
(4) T.M.M. Neue Folge., vol. VI., p. 129.
(5) N.J., 1882, vol. I., p. 163.

Whin Sill were strongly magnetic and at the same time contained 24 p.c. of titanic oxide.

Iron oxides are generally regarded as constantly occurring in the basic eruptive rocks as original constituents. Professor JUDD, however, holds that this is not the case in the gabbros of the West of Scotland. In these rocks the iron oxides do not appear to have separated out during the consolidation of the magma; they occur in cracks in the olivine and are regarded by him as the result of the "schillerizing" process. In rocks of the dolerite and basalt families, and their vitreous representatives, opaque iron oxides are constantly found. Their separation from the magma does not appear to be limited to any particular phase in the consolidation. In the metamorphosis of dolerite into hornblende schist the decomposition of the original titaniferous magnetite or ilmenite gives rise to the formation of small vividly polarising granules of sphene.

Black Mica. This mineral occurs in flat hexagonal tables. It possesses a perfect cleavage parallel to the basal plane. Sections at right angles to this plane show the cleavage cracks running parallel with the edges. They are lath-shaped in form and give straight extinction. They are also strongly dichroic; changing from a pale brown, when the short axis of the nicol lies at right angles to the length of the section to a deep brown, or almost black, when the short axis lies parallel with the length of the section (distinction from brown tourmaline). Sections parallel with the basal plane remain dark in all positions between crossed nicols, are not dichroic and give the interference figure of a biaxial crystal with small axial angle.

The minerals which remain to be noticed occur only in very small quantity or as occasional constituents of certain rocks. Quartz, as might naturally be expected, is very rare in the basic eruptive rocks as an original constituent. It is found in some of the more acid gabbros and dolerites (diabase), and is then frequently associated with felspar as a constituent of micro-pegmatite. It arises also as a secondary product in consequence of the alteration of the original constituents by surface agencies, and in this condition is not uncommon. Apatite is almost invariably found. It occurs as short stumpy prisms and also as acicular microlites. Cross-sections are hexagonal and the angles are usually sharp and well defined. It is generally colourless; but occasionally shows grey, blue or yellowish tints. The refraction is high. The double-refraction is slight and of a negative character. It is readily acted upon by acids and the solution gives with molybdate of ammonia the well known yellow precipitate. This test may be easily applied to microscopic sections and furnishes a ready method of distinguishing this mineral from nepheline. Apatite varies considerably in amount in different rocks, and in a few cases is extraordinarily abundant. It is always one of the earliest products of consolidation, and occurs therefore as inclusions in all the other minerals.

Zircon is now known to be a widely distributed mineral in all kinds of igneous rocks.[1] It is, however, more common in the acid than in the basic

(1) THÜRACK. Über das Vorkommen mikroskopischer Zirkone und Titanmineralien in den Gesteinen. Verhdl. d phys.-medicin Ges. Würzburg, 1884.

series. It occurs, as a rule, in short well formed prisms. Refraction and double refraction are very strong, and the character of the latter is positive. Even the smallest individuals give vivid chromatic polarisation. Professor ROSENBUSCH mentions the occurrence of beautiful crystals of zircon in the Whin Sill of Upper Teesdale. Tourmaline and axinite are sometimes found in basic igneous rocks, where they have been acted upon by granite. The former mineral occurs as columnar crystals. It may belong to the brown or blue variety (indicolite). The two varieties are sometimes seen to be arranged in a zonal manner in one and the same individual (see fig. I, plate XVII). Tourmaline is distinguished by its strong dichroism, the greatest absorption always occurring in longitudinal sections when the short axis of the nicol is at right angles to the length of the crystal section. Its double refraction is negative. Axinite occurs in certain basic eruptive rocks near their contacts with tourmaline-bearing granites; as, for example, near Penzance, in Cornwall. It occurs in a massive form as bluish-grey veins in the Chyandower quarry in association with tourmaline, and sometimes also as crystals.

Pyrites and magnetic pyrites (pyrrhotine) occur frequently as secondary products. The former may occur as crystals (usually cubic) or as irregular masses, the latter always occurs in irregular masses. They are opaque in thin section and can only be distinguished from magnetite by examination in reflected light, when they are recognised by their yellow metallic appearance. The latter is distingished from the former by its magnetic properties, by its bronze-yellow colour in reflected light and by the fact that it is soluble in hydrochloric acid. Copper pyrites is also found as a secondary constituent of basic eruptive rocks.

Zeolites [1] are frequently found in the rocks now under consideration, but their discrimination is attended with considerable difficulty. Analcime is easily recognised by its form and by its feeble and anomalous double refraction. It is found in association with other zeolites in dolerites of the Car Craig type (see fig. I., plate XX).

The carbonates of calcium, magnesium and iron are frequently present in basic igneous rocks that have been decomposed by surface agencies.

They occur in crystalline masses or as a fine crystalline powder scattered through the rock. Their very high double-refraction and the sharpness of their cleavage-cracks are the most useful characters for recognising them under the microscope. In examining slides of decomposed basic igneous rocks it is often advisable to uncover a portion of the section and treat it with dilute hydrochloric acid under the microscope, in order to free it from the carbonates and at the same time to determine the distribution of these substances in the rock.

One of the most interesting constituents of basic igneous rocks is metallic iron. A method for detecting this substance when present only in extremely minute quantities will be found described by Dr. ANDREWS, in the British Association Reports for 1865.

(1) A. LACROIX. Sur le diagnostic des zeolithes en l'absence de formes crystallines determinables. B.S M. 1885, p. 321.

The only constituent which remains to be considered is the interstitial matter. In the rocks of the gabbro-family this is entirely absent. In the dolerites and basalts it may or may not be present. The composition of the interstitial matter in any given case depends upon the composition of the original magma, and the character and amount of crystal-development which has taken place during the process of cooling. In some cases it is a rich brown homogeneous glass; more commonly it is a more or less colourless glass crowded with crystallites, microlites or skeleton crystals. By a gradual increase in the amount of glass the crystalline pass into the vitreous rocks. In the holocrystalline plagioclase-augite rocks with ophitic texture we have evidence that progressive crystallisation gave rise to the formation of interstitial matter which finally crystallised as augite. As a rule a homogeneous brown glass is rare in basic igneous rocks. Crystallites and microlites indicate that a certain amount of differentiation took place after the formation of definite crystals had ceased.

DESCRIPTION OF THE ROCKS.

In dealing with this portion of the subject we shall adopt that method of treatment which appears to accord best with what is known as to the geological relations of the different rock masses. The absence of homogeneity in rock masses which possess a certain amount of individuality so far as their mode of occurrence is concerned renders a rigid system of classification, based on mineralogical composition, unsuitable to the expression of geological facts. As matters stand at present the basic rocks which contain a considerable amount of original hornblende may be conveniently separated from those which consist essentially of plagioclase, olivine and pyroxene, or of secondary products (including hornblende), derived from these minerals. The former group, so far as bulk is concerned, appears to be completely subordinate to the latter. If we fix our attention on the holocrystalline representatives of the latter group we recognise the existence of two extreme types—the plagioclose-olivine rocks and the plagioclase-pyroxene rocks—and also of a number of intermediate forms, composed of the three essential minerals in varying proportions. If we wish to indicate the quantitative relations of the minerals in these intermediate forms we may do so by placing the names in the order of the relative importance of the minerals which they represent. Again, further complication is introduced by the fact that the pyroxenes may be monoclinic or rhombic. The former are usually designated by the general term, augite; the latter by the term, enstatite. The two pyroxenes may occur singly or together. If now we consider the textural characteristics of the basic eruptive rocks we notice every gradation from the coarsely crystalline variety, in which the sizes of the individual have to be measured by inches, to the compact variety in which the crystalline character of the rock can only be ascertained by the use of the microscope; and also every gradation from the holocrystalline to the vitreous condition. Moreover, every kind of rock has its porphyritic and non-porphyritic representatives. Having regard to the transitions which occur in every

direction, it will be seen that any method of treatment not based on broad geological facts must be, to a great extent, artificial. The only way in which we can produce a cut and dried system of classification—a so-called logical system—is by shutting ourselves up in our laboratories and ignoring transitional forms.

In what follows we shall, for convenience of description, consider first of all the coarsely crystalline rocks with granitic texture; and afterwards the medium grained, finely crystalline, compact and vitreous rocks of similar composition. The former usually occur as large intrusive masses, but sometimes also as dykes, sheets and veins; the latter occur as dykes, sheets, veins and lava flows. The vitreous condition is comparatively rare amongst basic eruptive rocks, and when it does occur is usually seen at the margins of dykes and, less frequently, of lava flows.

The term gabbro will be used as a family name for the granitic modification of the basic magma. (1) It is thus made to include a great variety of mineral aggregates. On the one hand we have the varieties due to the occurrence of the original minerals—plagioclase, augite, enstatite and olivine—in varying proportions; on the other hand we have the varieties due to the more or less complete alteration of the original constituents into secondary products, such as saussurite and hornblende. Troctolite, eucrite and norite thus become varieties of the great gabbro-family, depending on variations in the relative proportions of the original minerals; euphotide (Hauy) becomes a variety dependent upon the alteration of the original constituents into saussurite and hornblende.

Rocks of the gabbro-family are extensively developed on the west coast of Scotland, in the islands of Mull, Skye and Rum, and on the mainland in the peninsula of Ardnamurchan. They were named hypersthenite, by Maccullock, under the impression that the principal ferro-magnesian constituent was hypersthene. (2) Precisely similar rocks occur in the Carlingford district of Ireland, north of Dundalk Bay. The Scotch rocks have been studied microscopically by Professor Zirkel (3) and Professor Judd, (4) and the Irish rocks by Professor Von Lasaulx. (5) These rocks are of great interest in consequence of their geological age. The definite recognition of the fact that they belong to the Tertiary period has destroyed the illusion that all gabbros are necessarily pre-tertiary; and, at the same time, greatly discredited the view now rapidly disappearing from the minds of geologists, that petrographical characters can

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(1) It will be extended also to such rocks as those of Mosedale, near Carrock Fell, which contain quartz in addition to the augite or diallage and plagioclase. These may be termed quartz-gabbros. They are not typical basic rocks, but represent the transition from basic to intermediate rocks. They are the plutonic representatives of the andesitic dolerites. The Mosedale rock contains 56 p.c. of silica.

(2) Western Isles of Scotland. 1819.

(3) Geologische Shizzen von der Westkuste Schottlands. Z.D.G.G. Vol. XXIII., 1871, p. 1.

(4) Q.J.G.S. Vols. XLI. and XLII.

(5) T.M.M. Neue Folge. Vol. I., 1878, p. 427.

be relied upon as a test of chronological relations except in limited areas.

They occur in large eruptive masses, often forming mountains two or three thousand feet in height, and from these masses apophyses run out in different directions. The texture of the rocks is thoroughly granitic ; no trace of amorphous matter is ever found. The constituents of the rocks are plagioclase, augite, diallage, pseudo-hypersthene, enstatite, olivine, biotite, and magnetite. These constituents are present in very different proportions in the different varieties. Plagioclase, monoclinic pyroxene and olivine are the principal constituents. Enstatite and biotite occur locally in certain varieties. The magnetite of the gabbros occurs in cracks and as inclusions in the olivine. It is never, according to Professor JUDD, a direct product of the consolidation of the magma. Sometimes the olivines are rendered quite opaque by the large amount of secondary magnetite which has been developed.

As a general rule and having regard to the whole district, felspar is the most abundant and olivine the least abundant constituent. Cases frequently arise, however, in which the olivine is more abundant than the augite or diallage.

Nodules and contemporaneous veins are common in certain portions of the gabbro-masses, especially in the island of Rum. They are for the most part binary compounds of the essential minerals of the gabbros, but in some instances one mineral forms almost the entire mass of the nodule or vein. As a general rule the gabbros are granular in texture. In Skye and Ardnamurchan, however, porphyritic varieties containing felspar crystals, two inches in length, are occasionally found. These large crystals appear to have been formed before the consolidation of the ground-mass. They have sometimes been cracked and the pyroxenic material has penetrated and crystallised in the cracks. In the Isle of Rum the gabbros containing plagioclase, pyroxene and olivine are found in intimate association with troctolites, eucrites, picrites, and peridotites. This association is of great interest, because it is found to be an almost constant feature in all the great gabbro-areas.

All writers on the Scotch and Irish gabbros of Tertiary age who have studied the rocks with the microscope call attention to the frequent presence of parallel rows of minute rods or plates in each of the three principal minerals. As the nature and relations of these inclusions have been already discussed (see *ante*, p. 28), it is unnecessary to do more than refer to the subject in the present connection.

The occurrence of a rock belonging to the gabbro-family (troctolite) in the parish of Belhelvie, Aberdeenshire, has been noted by Professor BONNEY.[1] It occurs in association with serpentine. The troctolite is a moderately coarse-grained mixture of purplish-grey or whitish felspar, and dull dark-green serpentine. Coarser varieties occasionally occur; usually the felspar is to the serpentine in about the proportion of three to two, but occasionally a fragment is seen in which the former mineral distinctly

(1) On bastite-serpentine and troctolite in Aberdeenshire. G.M., 1885, p. 439.

predominates. Microscopic examination shows that the felspar is tolerably fresh, though frequently traversed by cracks, and that the serpentine is altered olivine containing kernels of the undecomposed substance. A small amount of diallage is present. In one slide the olivines were seen to be surrounded by a fringe-like border, consisting of two zones, an inner and an outer. The outer zone was composed of needles of actinolite or tremolite. Here we have a feature similar to that first described by TÖRNEBOHM. [1] in the "hyperite" of ÖLME, and subsequently noticed by J. BECKE in the olivine-gabbros of Langenlois, [2] in lower Austria, and Rosswein [3] in Saxony; also by G. H. WILLIAMS, in the peridotites near Peekskill, [4] and the gabbros (pyroxene-granulites) of Baltimore. [5] In the last mentioned case, however, the fringes occur round hypersthene instead of olivine. In all cases they are limited to the zone of contact of olivine (or hypersthene) and felspar; so that no doubt can arise as to their being due to a reaction between the constituents of these two minerals.

Gabbros occur also in the Carrick district of Ayrshire. [6] They consist of diallage and saussurite, and are exposed on the coast north of Lendalfoot. The saussurite is a dense white compact substance which is, as a rule, somewhat opaque under the microscope, and not capable of being resolved into distinct minerals. Here and there some colourless felspar containing acicular microlites may be detected. The diallage is partly replaced by uralite and actinolite. Associated with the gabbro is a remarkable rock, composed almost entirely of large sub-metallic crystals of diallage, frequently measuring two or three inches in length. Gabbro occurs also at Portsoy, in Banffshire, in the Islands of Unst and Fetlar, belonging to the Shetland group. [7] It is doubtless present in may other Scotch localities. Professor ROSENBUSCH mentions the occurrence of exceptionally beautiful norites at Kirkhill and Towie Wood, north-west of Ellen, in Aberdeenshire.

A group of rocks composed of two or more of the minerals plagioclase, diallage, a strongly pleochroic rhombic pyroxene, biotite, magnetite or ilmenite and hornblende, enters very largely into the composition of the Hebridean gneissic system of Sutherlandshire, in the neighbourhood of Scourie.

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(1) N.J., 1877, p. 383.

(2) T.M.M., Neue Folge. Vol. IV., 1882, p. 355.

(3) *Ibid*, p. 450. The Rosswein case is particularly interesting. The fringe is sometimes five or six millimeters wide. It is radially fibrous in structure, and consists of two zones. The inner zone shows a silky lustre. Detached portions give straight extinction, a symmetrical interference figure, and a negative bisectrix. In thin sections this zone is seen to consist of colourless individuals, possessing the cleavage of hornblende, and giving in cross section an interference figure indicating widely separated optic axes. These characters show that the mineral is a rhombic hornblende (anthophyllite). Magnetite occurs abundantly between the fibres of anthophyllite. The exterior zone is composed of green fibres which possess the extinction and other characteristics of actinolite. No magnetite occurs in this zone; the whole of the iron having been absorbed in the actinolite.

(4) A.J.S. Vol. XXXI., 1886, p. 35.

(5) Bull, U.S. Geol. Survey. No. 28 (1886), p. 43.

(6) BONNEY. Q.J.G.S., Vol. XXXIV., 1878, p. 769.

(7) See Dr. HEDDLE. Trans. Roy. Soc., Edin. Vol. XXVIII.

Some of the rocks have a massive habit and are closely allied to gabbro in composition and structure; most of them are gneissic. They have affinities with the anorthosite (Norian) rocks of Canada, and with the trap-granulites of Saxony. Many, if not all, of these were probably eruptive, but as this point is at present undetermined we shall describe them along with other rocks of doubtful origin.

The Lizard district. Turning now to England we note that the most important exposures of gabbro are undoubtedly to be found in the Lizard peninsula of Cornwall. They occur as large intrusive masses, and also as veins and dykes in the serpentine. The largest mass is that of Crousa Down. This is represented on the geological map as occupying an area of six or seven square miles. It forms the coast line between Coverack and Manacle Point, and is well exposed in low cliffs along the shore. Veins and dykes of a fine-grained "greenstone" (epidiorite or pseudo-diorite) occur in the gabbro, and these increase in number towards the north, until in the neighbourhood of Porthoustock the greenstone is the dominant rock.

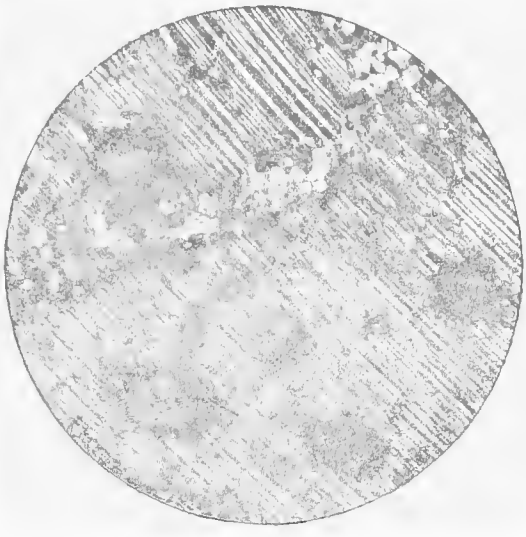
South of Coverack the greater part of the district is occupied by serpentine, in which veins and dykes of gabbro frequently occur. The mass which ranks next in importance to that of Crousa Down is exposed on the sea-coast west of Lankidden Cove. It forms the headland of Karakclews, and may be followed along the coast for a distance of about a quarter of a mile. A mass of similar gabbro occurs inland at Gwinter. The two portions are doubtless continuous, and, if so, they form a dyke-like mass running inland in a N.W. direction. The Karakclews gabbro is bounded on both sides by serpentine into which it sends veins and dykes. Another considerable exposure occurs on the shore north of Pen Voose, near Landewednack.

The principal constituents of the Lizard gabbro are plagioclase, augite or diallage, hornblende, olivine, and the dense white opaque substance known as saussurite. Iron oxides, except such as are undoubtedly of secondary origin, are rare or altogether absent.

The least altered rocks bear the closest possible resemblance to the Tertiary gabbros of the west of Scotland. In these rocks the plagioclase occurs in the form of grains of tolerably uniform dimensions in the different directions. The grains show broad lamellar twinning, and not seldom two sets of lamellæ are seen crossing each other at right angles. They are perfectly fresh. In the more or less altered gabbros we see various stages of the replacement of the felspar by white or cream-coloured saussurite.

The felspars of certain gabbros in which the development of saussurite has not taken place at all, or has only occurred to a very limited extent, often give evidence of having been affected by profound mechanical disturbances. The twin lamellæ are often bent. The extinction under crossed nicols is wanting in sharpness and definiteness. Cracks traverse the crystal and a felspar-mosaic has often been developed along the cracks. The final stage of this kind of metamorphism is represented by the replacement of the original crystal by a water-clear felspar-mosaic. These changes in the felspar are of course accompanied by changes in the other minerals, and by a modification of the original structure of the rock. Specimens of a felspar-diallage gabbro (eucrite) from Gwinter show the above features in the greatest perfection.

Fig. 22.



The replacement of the original felspar by a felspar-mosaic is illustrated in *figs.* 22 *and* 23. The photographs from which the figures have been prepared were taken under crossed nicols. In *fig.* 22 the greater portion of the field is occupied by the original felspar; it is, however, traversed by a band along which the mosaic structure has been developed. The individual grains of the mosaic are for the most part untwinned. In *fig.* 23 a much larger portion of the original felspar has been replaced by the mosaic. Traces of the original individual may, however, be followed across the area represented in the figure by the parallelism in the twin lamellæ.

Fig. 23.

The pyroxene of the least altered rock is a pale green diopside, containing only the incipient stages of diallagic structure. It is almost colourless in thin section, and precisely resembles the pyroxene of some of the Scotch tertiary gabbros. The normal pyroxene of the Lizard gabbros is a well-characterised diallage, often possessing a metallic lustre on the plane of easy separation. The replacement of diallage by hornblende is a common feature in the Lizard rocks. The secondary hornblende may be compact, uralitic or actinolitic. Actinolitic hornblende frequently forms radiating fringes round the uralitic variety, or round a crystal of diallage partially changed to uralite. Where the rock-mass has been subjected to deformation the diallage has frequently been replaced by confused aggregates of grains and fibres of hornblende. The secondary hornblende may be green, brown or colourless. Green varieties are very common. There seems no reason to believe that any of the hornblende in the Lizard gabbros is an original product.

The olivine may be either fresh or serpentinized. The fresh mineral is colourless, and traversed by cracks along which magnetite has been deposited.

In many rocks the olivine, where it occurs in contact with felspar, is surrounded by one or more zones. Sometimes unaltered olivine is separated from unaltered plagioclase by a narrow zone of a compact mineral, having the pleochroism of a rhombic pyroxene. This mineral is perfectly fresh, and the junctions with the olivine on the one side and felspar on the other are quite sharp. Considerable portions of the zone show uniform optic orientation. At other times the zones consist of fibrous minerals which show a rough tendency to a radial arrangement with respect to the olivine. This appears to be more common round altered olivines, and has much more the aspect of a secondary formation. In the most common case two zones may be recognised. The inner one consists of a colourless fibrous mineral which gives straight extinction. The outer one in contact with the felspar is green, and possesses all the microscopic characters of actinolite. Magnetite-dust usually occurs between the colourless needles of the inner zone, but is altogether absent from the outer zone. Seeing that these zones agree in character with those of the Rosswein rock, described by Becke, it seems probable that the mineral of the inner zone is anthophyllite.

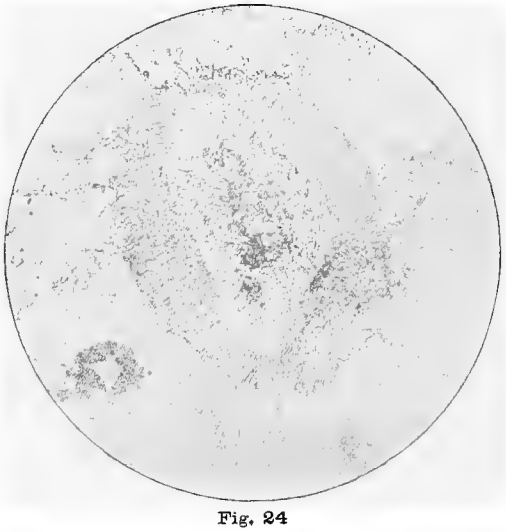


Fig. 24

In *fig.* 24 the central part represents altered olivine. Surrounding this is a zone of colourless anthophylite, and surrounding this again is a zone of radiating actinolite. The remaining portion of the figure represents comparatively unaltered felspar.

The original felspar-bearing rocks of the gabbro-family occurring in the Lizard peninsula comprised plagioclase-augite rocks, plagioclase-augite-olivine rocks (olivine-gabbros), and plagioclase-olivine rocks (troctolites).

The replacement of augite and diallage by the various forms of hornblende, and of felspar by saussurite has given rise to a number of other varieties. Two of the most important of these may be designated hornblende-gabbro or gabbro-diorite and saussurite-gabbro or euphotide. It is worthy of note that the saussurite-gabbros appear for the most part to have been free from olivine. One very common rock at Crousa Down is composed of clear glassy labradorite, often occurring in large crystalline plates, and uralitic or actinolitc hornblende. It possesses a marked greenish tinge, due to the hornblende. Associated with this rock is a black olivine-gabbro, in which the diallage has retained its character.

The olivine-grains are frequently zoned with the colourless mineral (anthophyllite) and with actinolite.

We have now to notice the structural characteristics of the Lizard gabbros. In the first place we notice varieties depending on variations in the sizes of the individual constituents. In the coarsest varieties, now mainly composed of saussurite and diallage, the individual constituents often measure as much as two or three inches across. These extremely coarse varieties are distributed with considerable irregularity through the finer grained rocks; not seldom, however, they occur as veins and dykes in the serpentine, and when this is the case there is no difference in the texture of the rock occurring at the margins and in the centre of the veins, a fact which suggests that they should be regarded rather as contemporaneous veins than as normal intrusive rocks.

The normal gabbro is a rock which may be simply described as coarsely crystalline. Fine grained varieties are not known. The mutual relations of the individual constituents in the unaltered gabbros are those of typical granitic rocks; in other words no single mineral appears to have possessed any special advantage over any other so far as the conditions favourable to the development of crystalline form are concerned.

In addition to variations of structure depending on variations in the sizes of the individual constituents, there are others dependent on the mode of arrangement of these constituents in the rock-mass. From this point of view the rocks may be divided into two groups: (1) the massive and (2) the foliated gabbros. These two varieties are not, however, separated from each other by any hard and fast line. In the massive gabbros the individual constituents are not arranged in any definite manner; in the foliated gabbros a parallel structure is more or less pronounced. In speaking of the foliated gabbros it is convenient to recognise two principal types which may be designated by the terms *flaser-gabbro* and *gabbro-schist*. In the flaser-gabbro the parallel structure, though distinct, is not accompanied by any marked

fissility. The constituents are saussurite and dark aggregates of diallage and hornblende. These constituents are more or less lenticular in form, and the flat surface of the lenticles lie parallel to each other, thus producing the foliated structure. The gabbro-schist is a rock of finer grain, with a strongly marked schistosity. It can be broken into flat slabs like a hornblende-schist, to some varieties of which it bears the closest possible resemblance. Although it is convenient to use the two terms flaser-gabbro and gabbro-schist, it must not be supposed that there is any hard and fast line between the rocks designated by these terms. They shade into each other by the most insensible gradations. One very interesting structural variety, in some respects intermediate between flaser-gabbro and gabbro-schist may be termed augen-gabbro. In this variety the streaks which define the schistosity sweep round "eyes" of diallage, which thus remind one strongly of the "eyes" of felspar in augen-gneiss (see plate XXVI). Foliated gabbros are admirably shown at Karakclews Headland, and north of the small bay locally known as Pen Voose, near Landewednack. The foliation is, doubtless, the result of the regional metamorphism which has affected the district since the formation of the gabbro. We have at present no very reliable evidence as to the age of the gabbro, or of the regional metamorphism. The occurrence of serpentine and gabbro at Nare Point, in association with Ordovician rocks, has been already referred to (see *ante*, page 123.) If the former are intrusive then they must be of post-Ordovician age. The Lizard gabbros are nowhere seen in relation with fossiliferous sediments, but they are probably of the same age as those of Nare Point. The apparent absence of pebbles of serpentine and gabbro from the conglomerates north of Porthalla is negative evidence which tells in favour of the view that the igneous rocks are of later date than the adjacent sedimentaries.

Next in importance to the Lizard gabbros are those of Anglesea and the Lake District. The Angelsea gabbros have been described by Professor Bonney. [1] Here, as at the Lizard and elsewhere, they were associated with serpentine. They occur in the western district, in Holyhead island, and the adjacent portion of the mainland. They consist of altered felspar and diallage; olivine is not mentioned as a constituent. In texture they may be either massive or schistose, and Professor Bonney mentions that "on the bank of an inlet near Tyddyn Gob is a rather schistose rock, which in the lower part resembles a foliated gabbro, in the upper a schist."

The Lake District gabbro occurs in the neighbourhood of Carrock Fell, and is remarkable for its intimate association with an acid augitic granophyre, into which it passes by insensible gradations, and also for the fact that it contains quartz as an original constituent. It is the plutonic representative of the andesitic dolerites. The rock was originally described by Mr. Ward [2] as a hypersthenite, under the impression that the dominant pyroxenic constituent was hypersthene.

Dr. Trechmann has pointed out that the supposed hypersthene is in

(1) Q.J.G.S. Vol. XXXVII., 1881, p. 40.
(2) Q.J.G.S. Vol. XXXII., 1876, p. 16.

reality diallage, and that the rock must therefore be classed with the gabbros. [1] An examination of a considerable number of microscopic sections shows that a rhombic pyroxene occurs sparingly; but not in sufficient abundance to remove the rock from the normal gabbros.

The rock is found on the south side of Carrock Fell. It is well exposed in the crags to the north of the small village of Mosedale. A striking feature of the mass is its variability in composition. Some specimens consist for the most part of ferro-magnesian constituents, others are mainly formed of felspar in association with quartz. The basic rock, as already stated, passes by insensible gradations into the acid augite-bearing granophyre (spherulitic felsite of WARD), which forms the actual summit of Carrock Fell. The mass not only shows variations in composition but also variations in texture. Some portions are coarsely crystalline and granitic, showing conspicuous crystals of diallage on the weathered surfaces; other portions are fine grained and ophitic in texture. Mr. WARD was much impressed with the existence of a kind of bedding in the mass a little south of the summit of Carrock Fell. Thus he says :—"Alternating with very coarsely crystalline layers are others of a very fine grain; the aspect of the rock from a little distance quite resembling the bedding among the volcanic series. Moreover, the dip of this bedding is tolerably constant along a line of strike answering to the strike of the volcanic series on the north, the dip being in this case north-wards, at angles of from 50° to 70°. Again, at the crags just north of Mosedale, there are most undoubted cases of beds of contemporaneous trap, alternating for short distances with hypersthenite, and passing into it along the east and west line of strike."

The mass is essentially composed of diallage, plagioclase and magnetite or ilmenite. Quartz is frequently present in the comparatively unaltered rocks, and there seems no reason to doubt that it was largely an original constituent. A rhombic pyroxene with distinctly marked pleochroism may be detected in some specimens. Biotite is common in some slides. The alteration products are uralite, actinolite, chlorite and other green minerals, together with ill-defined substances arising in consequence of the alteration of felspar.

The monoclinic pyroxene in a few cases shows the two prismatic cleavages only, and is then in the condition of augite. As a general rule, however, it exhibits a lamination parallel to the orthopinacoid (100), and contains the minute rod-like and tabular inclusions characteristic of diallage. The transition from the augitic to the diallagic condition may be observed in one and the same individual, as also the change from pyroxene to hornblende. The diallage is usually a pale brown in thin section; but in a few cases it exhibits a pinkish tint. Cross sections, showing an optic axis in convergent light, frequently exhibit a third cleavage parallel to the optic axial plane (010), as well as the two prismatic cleavages and the diallagic striation. In one case a clino-piacoidal section of a twinned crystal showed

(1) G.M. Decade II., Vol. IX., 1882, p. 210.

a striation parallel to the basal plane. It is interesting to note in one and the same rock the normal diallagic striation and also the similar striation parallel to the basal plane. The replacement of diallage by hornblende has been already referred to.

The rhombic pyroxene is now principally represented by a green fibrous dichroic mineral, giving straight extinction (bastite). In this alteration product we occasionally find portions of the unaltered enstatite, giving straight extinction, and exhibiting the characteristic pleochroism: pale green for rays vibrating parallel with the vertical axis, and pale brown for rays vibrating transversely. The intensity of the pleochroism is not great. In composition the mineral probably resembles bronzite.

The felspar varies in its state of preservation in different specimens. In some it is remarkably fresh. In these cases it exhibits fine striation, due to twinning on the albite plan. Two cases of symmetrical extinction on opposite sides of the trace of the face of composition were observed, in which each angle was as nearly as possible 26°, making for the double angle 52°. These observations confirm Dr. TRECHMANN'S suggestion that the felspar is labradorite. The existence of other felspars is of course not impossible. In addition to twinning on the albite type we may observe also twinning on the Carlsbad and pericline types. All these types may co-exist in the same individual.

What is very remarkable in this rock is the occurrence of *colourless well striated crystals of plagioclase in a matrix of clear crystalline quartz.* The freshness of the rock in which this occurs precludes the possibility of the quartz being a secondary product. In this respect the Carrock Fell gabbro is entirely different from any of the gabbros previously described. Another feature of great interest is the frequency with which the quartz and the felspar tend to form micro-pegmatitic aggregates. This is best seen in the rocks which form the connecting link between the gabbros and the granophyres. Here we find exquisite examples of the micro-pegmatitic structure. The section of a twinned crystal of felspar, showing externally an approach to crystalline form, may be seen to be surrounded with micro-pegmatite the felspathic portions of which are twinned in accordance with the central crystal. Here we have a relation similar to that so frequently occurring in the quartz-felsites, where a kernel of quartz is seen to be surrounded by a zone containing quartz which extinguishes simultaneously with the kernel. In the Carrock rock, however, it is the felspar which forms the kernel.

The biotite occurs irregularly in the rock. It is characterised by intense pleochroism. Sections at right angles to the vertical axis appear almost opaque when viewed with rays vibrating parallel to the cleavage cracks. This mineral passes into chlorite by alteration.

The quartz has been already referred to. It plays the rôle of matrix, and occurs as crystalline grains and also intergrown with the felspar as micro-pegmatite.

Magnetite or ilmenite is always present and sometimes very abundant. It occurs in crystals, and more frequently in large irregular grains with

rounded angles. Here and there it is seen to be partially changed to leucoxene. Apatite frequently occurs in good sized prisms. The texture of the rock is on the whole granitic; at the same time we frequently see a tendency on the part of the felspar to assume crystalline faces. Lath-shaped sections are common in certain slides, and when they occur they frequently penetrate the diallage; thus giving the rock a sub-ophitic texture.

We have now to consider those massive igneous rocks which resemble gabbro in composition, but differ in texture and mode of occurrence. These rocks vary from coarsely crystalline to compact, and from holocrystalline to vitreous. They occur as intrusive lenticles, sheets, dykes, veins, necks, and lava flows. They constitute the great dolerite group of Mr. ALLPORT. No hard and fast line can be drawn between them and the gabbros; and cases not unfrequently arise in which it is impossible to decide whether a rock should be termed dolerite or gabbro. A typical dolerite is a distinctly crystalline rock, composed essentially of plagioclase, augite, and magnetite or ilmenite. The plagioclase occurs in forms which give lath-shaped sections. The augite may be present as grains, irregular masses or crystals. A typical gabbro, as we have already seen, is a coarsely crystalline rock of similar composition, but of granitic texture. Both the felspar and the pyroxene occur as grains of tolerably uniform dimensions in the different directions. Moreover, in gabbro the pyroxene is usually diallage. It is important to note that these broad differences in texture and mineralogical composition are usually associated with differences in mode of occurrence. Gabbro is found in large amorphous masses, and dolerite in intrusive sheets, dykes and massive lava-flows.

If now we fix our attention on the rocks of the dolerite group we note that, in a broad and general way, there are differences between the rocks which occur as intrusive sheets, lenticles, and dykes, and those which occur as lava-flows. The former are distinctly, and in some cases even coarsely crystalline; they contain little or no amorphous interstitial matter; and in the majority of cases are not porphyritic. The latter are compact; they frequently contain a considerable amount of interstitial matter, and are often porphyritic. In some cases basic lavas assume a coarsely crystalline aspect in consequence of the extraordinary abundance of the porphyritic constituents. Careful examination, however, will show the presence in all these cases of a certain amount of fine-grained ground-mass between the porphyritic crystals. It must not be forgotten that the above statements with regard to the differences between intrusive and interbedded rocks are only true in a broad and general sense. Numerous exceptions will be pointed out in the detailed descriptions of the rocks.

The dolerite group is extremely rich in varieties. These varieties may be due to differences in original characters, or to the more or less complete obliteration of the original characters by the various metamorphic agencies. Consider first the differences between varieties of unaltered or comparatively little altered rocks. The most basic dolerites contain about 45, and the most acid about 55 per cent. of silica. The former have a specific gravity

of about 3 (excluding the vitreous rocks), the latter of about 2·8. The basic rocks shade into the intermediate rocks by the most insensible gradations, and considerable difficulty is experienced in deciding where the line of separation should be drawn. We shall have a practical illustration of this in dealing with the Tertiary dykes of the North of England and South of Scotland. The rocks of many of these dykes contain from 55 to 58 p.c. of silica, and so far as composition is concerned might, therefore, be considered with more appropriateness in the next chapter. We shall treat of them here, and indicate their special characters by speaking of them as andesitic dolerites and basalts.

Rocks of the dolerite group exhibit a wide range of variability so far as the size of the individual constituents is concerned. The term dolerite properly belongs only to the distinctly crystalline rocks. The compact varieties are usually termed basalt. Individual masses of dolerite usually show a considerable amount of uniformity in composition and texture. Sometimes, however, we find contemporaneous veins, nodules, and irregular patches differing from the main mass.

The occurrence of glass or other kinds of amorphous interstitial matter is an important feature of the rocks now under consideration. By an increase in the amount of glass and by a diminution in the amount of the crystalline matter the holocrystalline dolerites and basalts pass through the magma-basalts into tachylyte or basalt-glass. It has been proposed that the presence or absence of glass should be made the ground of distinction between dolerite and basalt—that the former term should be limited to the holocrystalline rocks, and the latter to rocks containing glass. The principal objection to this is that it would involve a considerable departure from the accepted use of the terms. Many distinctly crystalline rocks would have to be termed basalts; and many compact rocks would become dolerites. If the presence of glass were connected with any important textural, mineralogical or geological characteristics the departure from the generally accepted use of the terms would of course be justified; but such does not appear to be the case. It seems better therefore to retain the common use of the terms, for this roughly corresponds with broad geological facts. The dolerites usually form intrusive sheets or dykes and the basalts, lava-flows.

Another very interesting feature in rocks of the dolerite family is the fact that the order of consolidation of the two principal constituents, plagioclase and augite, is not always the same. In some cases the felspar precedes the augite (ophitic dolerites), in others the two minerals crystallize simultaneously (pegmatitic dolerites), and in others the augite precedes the felspar. The pegmatitic structure in dolerites is, so far as we know, extremely rare; but it is very interesting as furnishing an intermediate stage between the ophitic dolerites and the dolerites with idiomorphic augite.

The presence of porphyritic crystals gives rise to important varieties of basic igneous rocks. In some we find felspar (usually bytownite and less frequently labradorite) occurring as a porphyritic constituent; in others augite; in others both augite and felspar. It is important to note that

individual rock-masses usually exhibit a uniformity in the character of the porphyritic constituents; in other words we do not find the different types just referred to occurring together in one and the same rock-mass. Olivine sometimes occurs in sufficiently large crystals to give a porphyritic character to some of the basalts.

The presence of accessory minerals, such as olivine, enstatite (hypersthene) mica and hornblende, gives rise to additional varieties. We thus have olivine-dolerites, enstatite-dolerites, mica-dolerites and hornblende-dolerites. The occurrence of two or more of the accessory constituents gives rise to still more complicated forms.

So far we have been referring only to original characters. If now we take into consideration secondary characters, due to the operation of the various agents of metamorphism, the subject becomes still further complicated. Chlorite, zeolites, calcite, quartz and other minerals are developed by surface agencies. The members of the dolerite group associated with the older strata, and especially those of lower Palæozoic age, frequently contain chlorite. These constitute the typical diabases. Contact and regional metamorphism also produce important structural and mineralogical changes. Hence arise proterobases, epidiorites, and various schistose rocks.

A special feature of contact metamorphism is the development of a pale brown mica; and, less frequently, of such minerals as tourmaline, axinite and garnet.

It thus appears that members of the great dolerite-family vary in respect of the following characters:—

(1) Size of the individual constituents.
(2) Chemical composition.
(3) Mineralogical composition.
(4) Amount of glass or other interstitial matter.
(5) Relation of the pyroxene and felspar as regards the order of formation.
(6) Presence or absence of porphyritic constituents and the character of the porphyritic constituents when any are present.
(7) Extent and character of the metamorphism.

Owing to the large number of more or less independent variables the group is extremely rich in varieties. Some of these are of no special significance; others have a chronological, geographical, or geological value. To ascertain the relative value of the different characters is one of the most important problems awaiting solution.

In describing the members of the dolerite group and the changes to which they have been subjected it will be convenient to follow the plan adopted in other parts of the work and speak of them as they are developed in the different districts in which detailed observations have been made.

West of Scotland.—The Tertiary dolerites and basalts of the west of Scotland, and the north of Ireland first demand our attention. They form beds of great extent and thickness which must have flowed at the surface as lavas. They occur also as veins, dykes, and intrusive sheets. The medium grained rocks, or dolerites proper, are for the most part holocrystalline compounds of plagioclase giving lath-shaped sections, augite in irregular crystalline masses, magnetite or ilmenite, and olivine. They are in short, typical ophitic olivine-dolerites (see Fig. 1, Plate X.). Good illustra-

tions of this type occur close to the landing places at Portree and Tobermory, in the Shiant Isles, near Ardtornish Castle, and at Portrush in Antrim.

Rocks of precisely the same character have been described by BRÉON as occurring abundantly in Iceland[1] and the Faröe Isles. This author isolated the lath-shaped felspars and determined them by chemical analysis to be labradorite. In thin sections they frequently give extinctions of about 30°. There is therefore no doubt that this special type of dolerite is highly characteristic of the Tertiary volcanic district including Iceland, the Faröe Isles, the west of Scotland and the north of Ireland. If Figures 1 and 2, Plate X., of the present work be compared with Figures 1 and 2, Plate I., of M. BRÉON'S work on Iceland, the striking resemblance of the Scotch to the Icelandic rocks will be at once apparent. In addition to the ophitic dolerites we find others of the type with granular augites. The relation of these to the ophitic dolerites is sometimes clearly shown. Differential movement in an ophitic dolerites when it is near the point of final consolidation must lead to the breaking up of the irregular masses of augite into a number of grains and granules having independent optical characters. That such is the origin of some of the dolerites and basalts with granular augites is proved by the fact that transitions from the one type of structure to the other may be obtained in the same rock-mass and sometimes also in the same slide (see Fig. 2, Plate X.). Professor JUDD[2] has called attention to the existence, in the area now under consideration, of dolerites which approximate in structure to the trap-granulites of Saxony. "The most notable distinction in these rocks," he says, "is found in the character of the pyroxene and olivine grains, which, as seen in section, assume more or less rounded outlines, and are embedded in a plexus of lath-shaped crystals of felspar; in polarised light these grains are seen not to be parts of one large crystal, but to have very different orientations." Prof. JUDD proposes that the dolerites in question should be said to be granulitic. The ophitic structure is comparatively rare in the basalts, the augite for the most part taking the form of more or less rounded grains.

By a diminution in the sizes of the different constituents the dolerites pass by imperceptible gradations into the fine-grained and compact basalts. These present us with the same types of structure as the dolerites. Interstitial matter may be present in rocks presenting any of the above textural characteristics. When present in considerable quantities the term magma-basalt may be conveniently used. The gradual passage of magma-basalt into basalt-glass has been described by Professor JUDD, and the characters of this glass have been investigated by him in conjunction with Mr. COLE.[3] In no case is basalt-glass known to occur on an extensive scale in the West of Scotland. It forms narrow selvages, at most only 2 or 3 inches thick, to certain basaltic dykes. At present it appears to be recorded only from seven localities; at the Beal near Portree, in the Isle of Skye; at Lamlash (Holy Isle) Arran; at Sorne Point on the N.W. coast of the Isle of Mull; at Gribun in the west of Mull; at Screpidale in the Isle of Raasay;

(1) Géologie de l'Island, Paris, 1884.
(2) See JUDD, Q.J.G.S., Vol. XLII. (1886), p. 49.
(3) On the Basalt-glass (Tachylyte) of the Western Isles of Scotland. Q.J.G.S. Vol XXXIX., 1883, p. 444.

in the Castle Grounds at Brodick, in the Isle of Arran, and at the Quiraing in Skye.[1] The basalt-glasses are distinguished from the andesite- and liparite-glasses, which they closely resemble in external characters, by their high specific gravity and easy fusibility. The following table gives the specific gravities and silica percentages of the Scotch representatives of this group according to Messrs. JUDD and COLE :—

	Sp. Gr.	SiO_2.
The Beal, near Portree ...	2·72 ...	52·59 %
Lamlash, Arran	2·78 ...	56·05 ,,
Gribun, Mull...	2·82 ...	50·51 ,,
Screpidale, Raasay	2·84 ...	46·68 ,,
Sorne	2·89 ...	47·46 ,,
Brodick	2·83 ...	53·96 ,,

The specific gravity of the natural glass, in the majority of cases, bears the same relation to the associated basalt as that of the artificial glass to the rock from which it is obtained by melting. A remarkable and unexplained exception to this rule, first noticed by DELESSE, occurs in the case of the Lamlash dyke. The specific gravity of the basalt is 2·649 according to DELESSE and 2·67 according to Mr. DAVIES; that of the glass is 2·714 according to the former observer, and increases in passing outwards from 2·72 to 2·78 according to the latter observer. Prof. JUDD points out that the rock of the dyke is a magma-basalt in which only incipient crystallization has taken place, and suggests that the anomaly may be due to the fact that the central portions have been more altered than the exterior. The lustre of the basalt-glasses varies from resinous to vitreous. Sometimes, as in the case of the Beal mass, the glass shows a minute columnar jointing.

In thin sections the basalt-glasses above referred to are characterized by great opacity, due to the presence of finely distributed magnetic dust. Sometimes this dust is concentrated in nebulous masses of a more or less spherical form and then the isotropic and truly glassy character of the intervening substance can be ascertained. Perlitic structures may occasionally be observed. Porphyritic felspars frequently occur in the glassy matrix and these are usually fragmentary and completely honeycombed with inclusions. Olivines are occasionally present and, in the case of the Lamlash occurrence, augite has also been observed. Crystallites, microlites, and skeleton crystals are common and increase in amount and definiteness until the rock becomes a magma-basalt.

	I.	II.	III.
SiO_2 ...	52·59 ...	55·20 ...	56·05
Al_2O_3 ...	17·33 ...	16·98 ...	17·13
Fe_2O_3 ...	11·14 ...	11·00 ...	10·30
MnO ...	0·66 ...	tr. ...	tr.
CaO ...	6·47 ...	6·80 ...	6·66
MgO ...	2·62 ...	0·52 ...	1·52
Na_2O ...	4·24 } ...	5·65 (by diff.)	{ 3·29
K_2O ...	2·40 } ...		{ 0·98
Loss ...	3·27 ...	3·85 ...	3·50
	100·72	100·00	99·43

(1) Noted by DR. HEDDLE. M.M., Vol. V., p. 8.

I. Basalt-glass of the Beal, Portree.
II. Basalt from the centre of the Lamlash dyke (DELESSE. Ann. d. Mines, 1851.)
III. Basalt-glass from the side of the dyke (DELESSE, *loc. cit.*)

DELESSE'S analysis of the Lamlash dyke shows a higher silica percentage than is usual in basic eruptive rocks.

Porphyritic dolerites and basalts occur in the Tertiary volcanic districts of the West of Scotland. Felspar is the most important mineral which determines the porphyritic character. It occurs in broad platy crystals and not unfrequently shows a zonal structure. Augite seldom occurs in porphyritic crystals. Rocks of basaltic texture are often rendered porphyritic by the occurrence of olivine. Good examples of porphyritic dolerites occur at Dun-da-gu in the Isle of Mull, in the peninsula of Ardnamurchan, and at the Carlingford mountain in Ireland. On the north-east side of Mull, between Tobermory and Ardnacroish, Prof. JUDD found a basalt containing felspar crystals measuring more than two inches across. The Tertiary porphyritic dolerites resemble many of the rocks which have received such names as labradorite-porphyry and diabase-porphyrite, both in structure and composition. By a disappearance of the olivine and a reduction in the amount of the ferro-magnesian constituents they pass into rocks of intermediate composition. At Fair Head, Co. Antrim, occurs a remarkable variety of porphyritic dolerite. The ground-mass of the rock is ophitic. The porphyritic elements, instead of being individual crystals, are aggregates of anorthite and olivine which range from a tenth to one-third of an inch in diameter. The mutual relations of the anorthite and olivine are the same as those which characterize troctolite or forellenstein. Prof. JUDD has proposed that the term glomero-porphyritic should be used to designate the structure of this rock.

The Continental basalts of Tertiary age often contain nodules of peridotite. These nodules may consist of olivine only, or of olivine in association with enstatite, chrome-diopside and picotite. They may measure only a fraction of an inch or several inches in diameter. It is worthy of note that no such nodules have ever been detected amongst the Tertiary basalts of Great Britain and Ireland.

The only kinds of change to which the rocks now under consideration have been subjected are those due to surface agencies, and possibly to steam and other gases originating in connection with the final stages of volcanic action in the district. There is no evidence of the alteration of extensive masses into diabases, melaphyres, and wackés by surface agencies, or of the development of schistosity, with its corresponding mineral changes, by dynamic metamorphism. Nevertheless, we do find here and there illustrations of the development of chlorite by the alteration of augite; of serpentine by the alteration of olivine; and of kaolin and other products by the alteration of felspar. Zeolites have also been extensively developed. The alteration of augite into vermicular aggregates of chlorite, similar to those represented in Fig. 2, Plate XXII., is well seen in the case of a dolerite from Ardtornish.

Midland Valley of Scotland.—This district was the site of intense volcanic activity during Old Red Sandstone times, when immense masses

of andesitic lava and tuff (now porphyrite and porphyrite-tuft) were erupted. The activity was prolonged into Carboniferous times, but a change took place in the character of the volcanic material. Basic rocks were then formed on a large scale. These rocks have been described by Mr. ALLPORT[1] and Dr. GEIKIE.[2] They form amorphous masses, intrusive sheets, dykes and veins, contemporaneous lava-flows, and tuffs.

Again, the highest members of the Carboniferous formation contain ntrusive sheets of basic material and volcanic necks. These must be, as Dr. GEIKIE pointed out, either late Carboniferous or post-Carboniferous. It is difficult to fix their exact age. Dr. GEIKIE refers them somewhat doubtfully to the Permian period. Lastly, we find in the same district a series of E. and W. dykes which may, with very considerable confidence, be referred to the Tertiary period.

The basic igneous rocks of the Midland valley are thus seen to belong, in all probability, to three distinct periods; Lower Carboniferous, Upper Carboniferous or Permian, and Tertiary. Our information as to the petrographical characters of the rocks is not as complete as could be desired; at the same time Mr. ALLPORT and Dr. GEIKIE both agree that there is a close resemblance between the rocks of the different periods. It is possible, however, that differences may be observed between the rocks of different periods when attention is paid to minute peculiarities of structure and composition. We find, for example, in the area under consideration, rocks containing porphyritic augites and a ground-mass composed of minute, well-formed crystals of augite in a felspathic matrix. Such rocks are at present unknown in the Tertiary volcanic district of the West of Scotland.[3] Again, some of the later intrusive sheets are enstatite-bearing dolerites, allied to the Whin Sill. It is impossible at present to estimate the value of the characters above referred to; nevertheless the above facts certainly deserve the careful attention of those who possess opportunities for investigation.

Dr. GEIKIE recognises the existence of six more or less distinct volcanic districts in the eastern portion of the Midland Valley. They are as follows:—(1) The district of Edinburgh; (2) that of East Lothian or Haddingtonshire; (3) that of West Lothian or Linlithgowshire; (4) that of Stirlingshire; (5) that of West Fife; and lastly (6) that of East Fife.

In the Edinburgh district lavas and tuffs, interbedded with the Calciferous Sandstone series, form the eminences of Arthur's Seat, Calton Hill and Craiglockhart Hill. The earliest of these belong to the basic, the latest to the intermediate series. Intrusive sheets and irregular masses also occur in the district. Arthur's Seat is a complex mass of igneous

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(1) On the Microscopic Structure and Composition of British Carboniferous Dolerites. Q.J.G.S. Vol. XXX. 1874, p. 553.

(2) Carboniferous Volcanic Rocks of the Basin of the Firth of Forth. Trans. Roy. Soc. Edin. 1880 p. 486.

(3) Prof. HULL long ago (G.M. Vol. X. 1873, p. 153,) called attention to a difference between the Limerick (Carboniferous) and Antrim (Tertiary) trap rocks depending on the occurrence of well-formed augite-crystals in the former.

products about the relations of which there is some difference of opinion. Dr. GEIKIE[1] holds that we have here the record of two district series of volcanic eruptions; the one belonging to the Calciferous Sandstone, the other to a much later period, probably the Permian. Prof. JUDD, on the other hand, maintains that both sets of volcanic products belong approximately to the same period, viz., to the Lower Carboniferous.[2]

The rocks of the Long Row, Haggis Knowe and St. Anthony's Chapel belong to the earlier series. They are finely crystalline rocks of porphyritic but not conspicuously porphyritic texture. The porphyritic constituents are felspar, olivine and augite. The ground-mass is composed of lath-shaped plagioclase, magnetite and minute granules of augite. Serpentine and chlorite are abundant in certain specimens. The rock was originally an olivine-basalt. Fluxion structure is sometimes well shown in the arrangement of the minute plagioclase crystals.

One of the most remarkable rocks of the district is the olivine-basalt of the Lion's Haunch. It belongs to the later series. It is a black rock which is rendered conspicuously porphyritic by crystals of augite, felspar and olivine. The augite crystals show the common forms (see Fig. 1, p. 157) and are frequently well exposed on a weathered surface of the rock. They often measure an eighth of an inch or more in length. The felspar (probably bytownite) occurs in thick tabular crystals. Sections exposed on a fractured surface are often a quarter of an inch in length, and show well marked striation on the basal cleavage. The lustre of the cleavage surfaces is often interrupted by the presence of inclusions. Olivine is very abundant and wonderfully fresh. It appears as yellowish green oily looking spots on a freshly fractured surface and may be readily detected without the use of the lens. All the porphyritic constituents of this beautiful rock may be determined without even the use of the pocket lens. Thin sections show that the above constituents lie in a ground-mass composed of minute granules and crystals of augite, crystals and grains of magnetite and colourless felspars which sometimes give lath-shaped sections, and sometimes appear as irregular plates. Felspar appears to play the rôle of matrix in the ground-mass and amorphous interstitial matter is rare, or present only in very small quantity. The porphyritic olivine crystals illustrate all stages in the process of serpentinisation, but are generally very fresh.

The rock on the east side of Dunsapie Loch, mapped as an interbedded lava of Lower Carboniferous age, bears many points of resemblance to that just described. The same minerals occur in it in very much the same relations but in different proportions. The porphyritic elements are often so numerous as to give the rock a coarsely crystalline appearance. This and the comparative rarity of olivine are the two principal characters which distinguish it from that just described. Under the microscope porphyritic felspars are seen to be always repeatedly

(1) Geology of Edinburgh.
(2) Q.J.G.S. Vol. XXXI., 1875, p. 131.

twinned on the albite plan, and the high extinction angles show that they belong to a species allied to anorthite. The augite is distinctly pleochroic in reddish brown and yellow tints. The olivine is markedly yellow in some sections (hyalosiderite), and passes into a rich deep green serpentine. This is an important and constant feature in the basic eruptive rocks of Britain, and is well illustrated also in the dolerites of the Midland Counties of England. Colourless olivines weather into pale green or yellow serpentinous products; yellow olivines, that is olivines which appear yellow in thin section (hyalosiderites), weather into deep green or orange yellow alteration products. Another feature in the fresh olivines of this rock is the occurrence of cracks containing segregations of magnetite. The ground-mass is essentially similar in composition to that of the Lion's Haunch rock, but differs in the fact that the small augites constantly occur as extremely minute and well formed crystals which lie embedded in a matrix of felspar. These augite microlites are prismatic in form and are often many times longer than broad.

The rock of Sampson's Ribs is similar to that of the Long Row in its petrographical characters. It is a porphyritic basalt.

We have now to notice the rocks which occur as intrusive sheets in the neighbourhood of Arthur's Seat.

Salisbury Craig is formed of a medium grained granular rock described by Mr. ALLPORT as containing "visible crystals of felspar and augite with numerous grains of calcite, analcime, and two minerals which appear to be prehnite and pectolite..... Thin slices exhibit under the microscope considerable variations in texture; in all, however, there are crystals of plagioclase, orthoclase, [?] augite, magnetite and apatite with more or less of glassy base. The augite varies in shade from light brown to purplish brown, the latter being slightly dichroic; in the more highly altered specimens this mineral is converted wholly or in part into pseudomorphs of a greenish brown granular substance. Those portions of the rock which contain calcite and zeolites may have been slightly vesicular originally; but the mode of occurrence of these substances seems rather to indicate that they have replaced a glassy or felsitic matrix [pseudo-amygdules]. In some specimens comparatively large spaces are filled with calcite and analcime; the latter may easily be mistaken for the glassy base, as it belongs to the tesseral system, and is therefore devoid of double refraction.(1) It occurs, however, in distinct crystalline forms of eight sides, which are no doubt sections of trapezihedrons the most common form of the mineral. Chlorite in vermicular crystals and also grouped in rosettes, occurs in the calcite and analcime, and is also disseminated throughout the mass. Some specimens of this rock are far more highly altered than others."

The rock of the irregular ridge known as the Dasses is rendered conspicuously porphyritic by the occurrence of large felspar crystals in a

(1) This mineral occasionally shows anomalous double refraction like that of many other crystals which are isotropic at the of time their formation.

dull green matrix. It is much altered and may be termed a diabase-porphyrite. Corstorphine hill,[1] three miles west of Edinburgh, is formed of a mass of basic igneous rock, intrusive in the Calciferous Sandstone series. The rock was originally a holocrystalline ophitic olivine-dolerite. It is now composed of very large irregular masses of augite which play the rôle of interstitial matter, greyish pseudomorphs after lath-shaped felspars, crystalline plates and irregular masses of ilmenite, often more or less changed to leucoxene, green aggregates (viridite or serpentine) occasionally showing the form of olivine, epidote, calcite, quartz and zeolites. Good specimens of prehnite and pectolite may be obtained in veins and cavities in the rock. The felspar of this rock has been profoundly altered and rarely gives the distinct reaction of this substance under the microscope. The augite on the other hand is remarkably fresh.

The rock of Dalmahoy Hill has been described by Mr. ALLPORT and by the author of Cole's Microscopical Studies.[2] It forms an intrusive sheet in Carboniferous shales and sandstones. Mr. ALLPORT describes it as a black dolerite of distinctly crystalline texture composed of plagioclase, augite and magnetite, with yellowish green pseudomorphs after olivine. The felspar is quite unaltered and exhibits coloured bands in polarized light. Apatite occurs sparingly, in long hexagonal prisms. The spaces between the larger constituents are filled with a felsitic and cryptocrystalline mass instead of the usual glass; in one section this substance also occurs as a small vein and is crowded with minute hexagonal plates of specular iron. The felspar of this rock gives sections which are broad in proportion to their length. The augite occurs in good sized grains and granular aggregates and is not interfered with in any conspicuous manner by the felspars; in other words the rock is not markedly ophitic. One of the most interesting constituents is the interstitial matter which is present in considerable quantity. It is rendered brown by indistinct granular matter, and contains microlites and skeleton crystals of felspar. The forms of the skeleton crystals remind one of those represented in Fig. 7, page 15. Olivine is certainly rare in this rock, but seems to be occasionally represented by pseudomorphs.

At Ratho, nine or ten miles west of Edinburgh, occurs a mass of coarse grained dolerite of somewhat variable aspect. The rock is composed essentially of plagioclase, augite and magnetite. A coarse grained variety from the quarry by the canal contains long, bladed augite crystals with traces of diallagic striation parallel to the basal plane. Micropegmatite is present and plays the rôle of interstitial matter between the felspars. A specimen from Norton quarry contains, in addition to the above constituents, a rhombic pyroxene which, from its pleochroism, may be identified as hypersthene. In the character of the augite, as well as in the presence of

(1) VOGELSANG describes and figures a basalt from Podlie Crag near North Berwick, (Die Krystalliten, p. 119 and Fig. 1, Plate XIII.). It contains crystals of augite, felspar and probably psuedomorphs after olivine in a ground-mass which is remarkable on account of the presence of numerous skeleton crystals of magnetite (the rows of grains are grouped in straight lines which are often related to each other as the axes of cubic crystals) and augite.

(2) November, 1882, No. 26.

micropegmatite and a rhombic pyroxene, this rock resembles certain portions of the Whin Sill. A similar rock occurs at Kilsyth and Stirling. Such rocks when they contain hypersthene may be conveniently termed hypersthene-dolerites.

A special type of rock occurs on the Island of Car Craig, near Inchcolm, in the Firth of Forth (see Fig. 1, Plate XXII.). It is a medium grained granular rock, largely composed of well formed prismatic crystals of augite which may be recognized by the use of a hand lens. The other constituents are felspar, often much altered, analcime, natrolite (?) magnetite or ilmenite, a brown mica, and green decomposition products giving aggregate polarization. The brown mica is especially common in the most altered portions and often occurs as inclusions in the zeolites. It is almost certainly of secondary origin. In thin sections the augite is seen to be somewhat variable in colour, often assuming a marked reddish brown tint, in which case it becomes decidedly pleochroic. A striking feature of this rock is the abundance of analcime. Unless soda has been introduced this would seem to imply the existence either of nepheline or a soda-lime, rather than a lime-soda felspar. This rock possesses marked affinities with the teschenites.

In the district of West Lothian or Linlithgow basic lavas and tuffs occur in the Calciferous Sandstone and Carboniferous Limestone. Their total thickness is about 2,000 feet. The picrite of Bathgate, already referred to, occurs in this district. There are also intrusive sheets in the Millstone Grit and Coal Measures; and east and west dykes, probably of Tertiary age.

The contemporaneous volcanic rocks of the Stirlingshire district are principally porphyrites and porphyrite-tuffs, like those of the Garlton Hills in Haddingtonshire, and they belong to the same period, that is to the Calciferous Sandstone series. There are also, according to Dr. GEIKIE, "thick sheets of dolerite and other pyroxenic rocks which extend from the neighbourhood of Kilsyth round the base of the Campsie Fells to beyond Stirling. These masses have been intruded among the Carboniferous Limestone strata, probably at a time before the consolidation and disturbance of these strata, seeing that they have been faulted and bent together with them. They belong to an extensive belt of intruded matter which, keeping not far from the base of the Carboniferous limestone series, extends to near the east end of the long county of Fife and forms in its course the prominent eminences of the Cleish, Lomond and Ceres Hills. We cannot be quite sure of the dates of these masses; some of them no doubt belong to the volcanic phenomena of the Carboniferous period, but some may be post-Carboniferous or even Tertiary." Mr. ALLPORT says [1]:—"South of the Kilsyth Hills there are several masses of dolerite belonging to the intrusive sheets; they occur at Croy, Gernal Brae, near Over Croy, and at the foot of the hill a little south of Kilsyth. Specimens taken from the above localities are almost undistinguishable from those collected at Ratho and West Craigs, near Edinburgh."

We have already seen that the Ratho rock is, in places, a hypersthene-

(1) Q.J.G.S. Vol. XXX., 1874, p. 561.

bearing dolerite containing augite with basal striation. A specimen from the Kilsyth quarry is a sub-ophitic dolerite composed of plagioclase, augite, hypersthene and ilmenite or magnetite. The hypersthene is markedly pleochroic, gives straight extinction and weathers into a deep green alteration product. We have already noted that olivines, rich in iron, weather to a deep green serpentine, whereas those poor in iron weather to a light green. Precisely the same is true of the rhombic pyroxenes. The strongly pleochroic hypersthene of the Kilsyth rock gives rise to alteration-products much deeper in tint than the feebly pleochroic bronzite of the Whin Sill. Specimens from Croy and Stirling show the augite with striation parallel to the basal plane. It would be interesting to know whether these rocks are contemporaneous with the Whin Sill which they resemble in so many respects and also whether the intrusive rocks of Fife, referred to by Dr. GEIKIE as occupying the same relations to the Carboniferous strata, are similar in their petrographical characters. In the West of Fife basaltic lavas and tuffs occur in the Calciferous sandstone series and in the lower part of the Carboniferous limestone. Various intrusive rocks also occur. In the east of Fife interbedded volcanic rocks are rare; the most striking feature of the district being the occurrence of volcanic necks now filled with lavas and fragmental rocks.

A general examination of the plagioclase-augite rocks of the Firth of Forth led Dr. GEIKIE to recognize three principal types:—(1) the diabases or granitoid type; (2) the dolerites and (3) the basalts. The rocks referred to as diabases are coarsely crystalline and not porphyritic; they occur as intrusive masses, sheets and bosses. The constituents are felspar, augite, titaniferous iron ore and apatite. The felspar is generally kaolinised. Binary Carlsbad twins are very common, and hence Dr. GEIKIE was led to the conclusion that orthoclase is frequently present.(1) The augite sometimes occurs in eight-sided prisms and sometimes as large irregular ophitic masses. It is as a rule unaltered. Olivine has not been certainly recognized in these rocks. Apatite sometimes occurs in stout dusty prisms and sometimes as minute colourless needles. Calcite, prehnite, pectolite and analcime are known as minerals in these rocks. Pyrite is generally present. Chalcedony and quartz also occur. Illustrations of this type may be seen in Lindsay's Crag, near Kirkliston, at Crossal Hill, near Dalmeny; at Muchraw, near Torphichen, at Auchensteary, near Kilsyth, and at Croy and the Carron Water above Denny.

Rocks of the above type shade into the dolerites. These latter rocks are markedly crystalline, except at the edges, where they become compact. They are uniform in texture, and seldom become porphyritic or amygdaloidal. In some cases they are holocrystalline; in others they contain a certain amount of glassy interstitial matter They consist of plagioclase, augite, titaniferous iron ore and apatite. Olivine is rarely present, and in

(1) The felspar of these rocks is often pink. Hence, in hand specimens they remind one of syenite rather than diabase. If the felspar consists of orthoclase to any considerable extent they might be termed augite-syenites.

this respect they differ from the basalts. The augite occurs as definite crystals or as irregular masses. The felspars frequently penetrate the augite, thus showing that, as a rule, the latter constituent was the last to form. Granules of augite are rare in this group, whereas they are extremely common in the basalts. The dolerites occur as intrusive masses which frequently exhibit very interesting phenomena at their junction with other rocks. The change as the margin is approached is thus described by Dr. GEIKIE:—"The irregular plates of augite gradually give place to minute granules. The same change is observed in the plates of iron ore, in which case the minute specks group themselves as club-shaped bodies. Felspars retain their form but become smaller; they often tend to arrange themselves with their longest diameters parallel to the bounding surfaces, but remain quite distinct right up to the margin. Sometimes the oxides take the form of a geometrically perfect network of interlacing rods. Where the invaded rock is a sandstone the junction is sharp and the sandstone is apt to break away; where it is an argillaceous shale a thorough welding of the two rocks takes place. In such cases the dolerite at the actual junction shows a still further diminution in its component particles. It becomes a dark opaque rock, which in thin slices under the microscope is found to be a mottled or curdled segregation of exceedingly minute black grains and hairs in a clear, glassy matrix, in which the augite and felspar are not individualized. But even in this tachylite-like rock perfectly formed and sharply defined crystals may be observed." Good illustrations of the change which takes place at the margins of intrusive masses of dolerite may be observed at Hound Point, in Linlithgowshire, and at the Salisbury Crags, near Edinburgh.

The term basalt is limited by Dr. GEIKIE to the contemporaneous lavas of basic composition. They consist of a compact or finely granular ground-mass through which crystals of plagioclase, augite, and olivine are scattered. The basalts are more often columnar than the dolerites. They exhibit a marked tendency to become slaggy and amygdaloidal at their external surfaces. The more distinctly crystallized basalts, such as those of Craiglockhart Hill and the Long Row, near Edinburgh, are termed anamesites by Dr. GEIKIE. The ground-mass of the rocks of the basalt group is ormed of minute lath-shaped plagioclase, granules of augite, magnetite, and a variable quantity of glass.

Contemporaneous basalt-lavas and intrusive sheets of dolerite are found associated with the Carboniferous strata of the western portion of the Midland Valley of Scotland, and, as would naturally be expected, they bear a very close relation to the rocks just referred to. For a description of some of these rocks we are indebted to Mr. ALLPORT.[1] The rock forming the "Hill of Dun," at Bowling, three miles east of Dumbarton, resembles in composition that of the Lion's Haunch, from which it differs merely in the fact that the felspars of the ground-mass are more decidedly lath-shaped, and often exhibit a beautiful arrangement due to fluxion.

A very interesting variety of basalt is described by Prof. ZIRKEL,[2] from

(1) British Carboniferous Dolerites, Q.J.G.S., Vol. XXX., 1874, p. 558.
(2) Basaltgesteine, Bonn, 1870, p. 139.

Dunglass, in Strathblane, ten miles N.N.W. of Glasgow. It is composed of lath-shaped felspar, altered olivine and augite in a glassy globulitic base. The globulites are extremely minute yellowish brown or brown bodies, the largest of which are only ·004mm. in diameter. Where these bodies are very numerous the glass appears a dark brown. They are without action on polarized light. Prof. ZIRKEL remarks that the poverty of this rock in augite is compensated for by the abundance of the brown globulites in the base.

Near Skilliangow, on the south slope of the Campsie Fells, occurs a very beautiful porphyritic mica-bearing dolerite (or basalt). The augite is well crystallized, but contains numerous inclusions of magnetite and felspar. Owing to the abundance of the porphyritic constituents the rock has a coarsely crystalline aspect. Mr. ALLPORT has also described rocks from Neilston-side Hill, the Craig of Neilston, and Croft Head, near Neilston, on the south side of the Clyde, in Renfrewshire. The rock of the Craig of Neilston is an exceptionally good illustration of a basalt largely consisting of minute columnar crystals of augite in a felspathic matrix.

Among the intrusive sheets of the Clyde Basin Coal-field that of the Necropolis Hill, Glasgow, deserves special mention. It is a micaceous dolerite of the Car Craig type (see ante p. 191). The rock of Deniston Hill is similar in character, but contains veins in which augite and hornblende (basaltic hornblende) are present (see Fig. 1, Plate XIII.). Hornblende is occasionally found in the rock of the Necropolis Hill. The amygdaloidal dolerite of Mugdock Tunnel, near Glasgow, furnished Mr. ALLPORT with a fine series of microscopic preparations illustrating the changes which igneous matter of basic composition is subject to. "The least-altered portions of the compact dark coloured varieties show that the rock consists of augite, plagioclase, magnetite, and serpentinous pseudomorphs after olivine, together with much disseminated chlorite, some of the augite and felspar being but slightly altered. In other specimens the whole of the constituents are converted into pseudomorphs, still retaining the original forms of the crystals, and there are many small cavities filled with calcite, zeolites and vermicular chlorite. These compact varieties, having a micro-amygdaloidal structure, afford extremely interesting examples of alteration, and illustrate in a most satisfactory way the gradual progress of the various changes which have taken place."

It seems probable that the cavities referred to are in part, at any rate, not true amygdaloids but pseudo-amygdaloids, that is spaces determined by the decomposition of minerals "in situ," and filled with secondary compounds resulting from the interaction of the chemical substances which pass into solution under the influence of the percolating waters.

The southern portion of the Island of Arran is extremely rich in rocks of the group now under consideration. It contains also rocks which may be conveniently designated andesitic dolerites (or basalts) in order to indicate their relations to the rocks of intermediate composition. By some authors these rocks would be termed augite-andesites. It is a matter of indifference what we call them

provided we recognize their true characters and relations. They consist essentially of plagioclase, augite (mostly in grains) and magnetite, with a variable and sometimes a not inconsiderable amount of brown crypto-crystalline interstitial matter. Their silica percentage is higher (sometimes 59 per cent.), and their specific gravity lower (about 2·7 or 2·8) than the corresponding features in normal dolerites and basalts. In colour and general appearance they resemble the dolerites and basalts, but in composition they are somewhat allied to the andesites. Professor ZIRKEL[1] called special attention to the existence of quartz in some of these rocks. It is difficult to be certain as to the nature of this quartz. In some cases, as for example, in a dyke occurring to the North of Drumadoon Point on the West Coast, it appears to be a foreign ingredient. It occurs in rounded grains and each grain is surrounded by a zone which suggests that the magma has exerted a corrosive action upon it. The Tertiary dykes of the South of Scotland and North of England are for the most part andesitic dolerites. M. BRÉON has described somewhat similar rocks from Iceland as augite-andesites, and proved that they are later in date than the more widely distributed olivine-dolerites. The Heckla lava of 1845 is a rock of this type. Dr. GEIKIE has shown that the dykes of the West of Scotland frequently intersect the older sheets. Taking all these facts into consideration, it appears that the andesitic dolerites are later in date than the olivine-dolerites in the Brito-Icelandic province and that many of the great dykes belong to this later period.

The olivine-dolerites of Arran, so far as they have been examined, possess the ophitic structure in the greatest perfection. They occur in the sheet capping the Clauchland Hills and Dun Fion and in the southern portion of the Island between Dippin Point and Benan Head. Mr. ALLPORT describes the occurrence of three distinct sheets of dark trap near Kildonan Castle. The middle one is an ophitic dolerite of the Dun Fion type. The lowest and uppermost sheets are of andesitic dolerite. In the Allport collection in the British Museum there are sections of four dykes; one from the neighbourhood of Corrie, another from Glen Shirrag, a third from Torlin Water, and a fourth from the neighbourhood of Drumadoon Point. These are all sections of andesitic dolerites and bear the closest resemblance to sections of the Eskdale, Acklington, and Cleveland dykes. M. NECKER[3] estimated the number of dykes between Loch Ranza and King's Cross Point at 200, and the total number on the Island at over 1,000.

Of the numerous N.W. and S.E. dykes in the southern portion of Scotland only one, that of Eskdale, has been described in detail.[4] It is an andesitic dolerite (augite-andesite), composed of lath-shaped plagio-

(1) Geologische Skizzen von der Westkuste Schottlands, Z.D.G.G., Vol. XXIII. p. 28.

(2) Géologie de l'Islande, Paris, 1884.

(3) Documents sur les Dykes de Trap d'une Partie de l'île d'Arran. Trans. Roy. Soc. Edin., Vol. XIV., Part II., 1840, p. 684.

(4) Dr. GEIKIE. The "Pitchstone" of Eskdale. Roy. Phy. Soc. Edin., Vol. V., 1880, p. 219.

clase, granules of augite, magnetite, and a considerable amount of cryptocrystalline interstitial matter. Near the Manse of Eskdalemuir this rock presents a curious and anomalous structure. The central portion, which is about sixteen or eighteen feet broad, is vitreous, and on either side of this is a band about eight feet thick of the normal rock above described. The line of demarcation between the two portions is perfectly sharp. "The vitreous rock stands up as a wall, on the outer surface of which a curious series of polygonal reticulations may be observed. This external sculpturing arises from the internal prismatic structure of the vitreous band. The prisms are of course approximately horizontal, being directed from the nearly vertical walls of the band. Each consists of a central core of vitreous rock, with an external sheath of dull and, to the eye, apparently more crystalline and devitrified rock. It is the union of the sheaths of contiguous prisms which has formed these prominent ribs. Each rib is thus composed of the outer shell of two prisms, the dividing line between which is marked by a suture along the centre of the rib. Moreover each rib is cut into small segments by a system of close joints, which are placed generally at a right angle to the course of the rib. On breaking open the vitreous cores of the prisms, we perceive that the rock, deep iron black in colour, has a peculiar vitreous glaze, quite unlike that of an ordinary basalt; that here and there the black glass of the base is segregated into kernels, or irregular patches, in which can generally be detected one or more amygdules of chalcedony, but some of which have a black empty internal cavity; and that throughout the rock, devitrification has proceeded so far as to allow of the individualization of the triclinic felspar (of which distinct facettes may be seen with a lens), and evidently also of other minerals."

Under the microscope (see Fig. 1, Plate XXIV.), the glassy rock is seen to consist of lath-shaped plagioclase, small grains and crystals of augite, crystals of magnetite and a considerable amount of brown glass, containing in some parts (but not in the part represented in our figure) globulites, trichites, and microlites. The globulites often coalesce to form dart-shaped bodies, which are frequently seen to have clustered round the augite granules in a radial manner. Where this action has taken place, the glass has been bleached. Only 16·8 p.c. of the rock was found to be soluble after treatment for ten days in hydrochloric acid, with one boiling at the end of the period.

		I.		II.
SiO_2	...	58·67	...	65·49
Al_2O_3	...	14·37	...	14·66
Fe_2O_3	...	1·64	...	—
FeO	...	6·94	...	5·44
MnO.		tr.		—
CaO	...	7·39	...	3·73
MgO	...	4·65	...	1·57
K_2O	...	1·42		
Na_2O	...	3·01	...	not est.
H_2O	...	2·02		
		100·11		90·89

I. Analysis of the rock by Mr. Wilson.
II. Partial analysis of the kernels of glass

The bulk analysis shows that the rock is closely allied to the augite-andesites in composition. It is interesting to compare the kernels of glass with the bulk analysis. They contain more silica; less lime, iron and magnesia; and doubtless more alkali, although this point was not determined. They represent the acid residuum left after a certain amount of crystal development had taken place (see *ante* p. 43).

The Eskdale dyke, which, it must be remembered, presents the remarkable characters above described only in one portion of its course, has been traced from the Lead Hills in Lanarkshire to Liddlesdale (a distance of 45 miles), and for some miles further into England.

At Craighead, near Crawfordjohn, Lanarkshire, there occurs a very remarkable rock. It appears to be an abnormal variety of one of the N.W. and S.E. (Tertiary) dykes. It would have been described by the older petrographers as an augite-porphyry. Macroscopically, it consists of a large number of very perfect augite-crystals, often measuring 7 or 8 mm. in length, by 4 or 5 in breadth, lying in a greyish crystalline ground-mass. Under the microscope the augite is seen to be deeply coloured. It contains lath-shaped felspar and olivine as inclusions, and the felspars are arranged with their long axis parallel with the external faces of the augite. The ground-mass is composed of lath-shaped plagioclase, olivine, magnetite and a certain amount of interstitial matter. Apatite is very abundant. The olivines are very fresh and distinctly coloured. Magnetite has been deposited along the cracks, and this has taken place without the development of any trace of alteration in the olivine itself. The interstitial matter and the felspars appear to have been more or less affected by alteration; but no evidence of the development of analcime, as in the Car Craig rock, has been detected.

The Southern Uplands of Scotland are bordered on the south by a fringe of Lower Carboniferous rocks with which are associated contemporaneous volcanic products. These have not yet received detailed examination, but they belong in all probability, for the most part, to the intermediate series. They may be followed almost continuously from near Dunse, in Berwickshire, by Kelso, Ruberslaw, Langholm, Birrenswark, and the Annan to the mouth of the Nith, at the foot of Criffel. At Stickhill, north of Kelso, there occurs in this series a porphyritic olivine-basalt bearing many points of resememblance to the rocks near Arthur's Seat. It consists of good sized crystals of bytownite, augite, and olivine in a ground-mass essentially composed of rather short lath-shaped felspars (labradorite ?), granules of augite and magnetite.[1]

Highlands of Scotland.—Basic igneous rocks, essentially composed of plagioclase and pyroxene, are found associated with the gneisses and schists of this region. They have not as yet received much attention at the hands of petrographers. A dyke occurring in the Hebridean gneissic system of Sutherlandshire, near the village of Scourie, has been examined by the author of the present work, and has been already referred to as illustrating the

(1) Teall. G. M., Decade II., Vol X., 1883, p. 252.

passage of a massive igneous rock into a crystalline schist. It also illustrates the passage of a massive plagioclase-pyroxene rock into a massive plagioclase-hornblende rock (epidiorite). The general course of the dyke is N.W. and S.E.; that of the gneissic banding is E.N.E., and W.S.W; so that the dyke cuts across the banding. The age of the dyke is not at present known. Those portions of the dyke which have retained their original characters consist essentially of plagioclase, pyroxene, and titaniferous iron-ore. The plagioclase often gives lath-shaped sections. It penetrates the grains and plates of pyroxene and possesses all the characters of the plagioclase of doleritic rocks. The pyroxene is pale in colour, and for the most part irregular in form. Sometimes it shows diallagic structure and sometimes not. The inclusions are seen to be arranged in a rude kind of zonal manner in some of the grains. The opaque iron-ore occurs in irregular plates. The rock is of medium grain, that is, the different constituents can be recognised with the naked eye or with a lens of low magnifying power. Every gradation from a rock of the above character (see Fig. 1, Plate XIX.), to one essentially composed of plagioclase and hornblende (see Fig. 1, Plate XX.) can be observed. The gradual replacement of the pyroxene by hornblende is the most striking feature. The change appears to commence at the margins of the pyroxene-grains and to proceed until all traces of the original mineral have disappeared The resulting hornblende may be fibrous, actinolitic, or compact. It often occurs as extremely ragged plates, containing detached granules of a water-clear mineral having the refraction and double-refraction of quartz. The forms of the original pyroxene-grains are for the most part lost, so that the replacement of pyroxene by hornblende cannot be strictly described as a case of either pseudomorphism or paramorphism. The modification of the pyroxene is accompanied by a modification of the felspar. In the epidiorite this mineral usually occurs as aggregates of irregular water-clear grains, in which needles and grains of hornblende occur as inclusions. In the least altered plagioclase-pyroxene rock the felspar is usually more or less turbid on account of alteration or the presence of minute inclusions; in the epidiorite the felspar is remarkable for its freshness. The outlines of the felspar-areas in the epidiorite do not correspond with those of the felspar-areas in the original rock. The micro-structure of the original rock, determined by the successive crystallization of the different constituents from an igneous magma, has been almost entirely obliterated by the subsequent changes. Rocks having the structure and composition of the epidiorite (Fig. 1, Plate XX.) are by no means rare in the Highlands of Scotland, and an important question arises as to whether they are in all cases the result of the metamorphism of plagioclase-pyroxene rocks. All that can be said with safety at present is that such rocks have been proved to have been formed by the metamorphism of plagioclase-pyroxene rocks and have not been proved to originate in any other way. There is no evidence to show that such rocks can be produced by the consolidation of an igneous magma. The Scourie dyke also furnishes evidence of the passage of a massive rock into a

crystalline schist. The change may occur in the space of an inch, as may be seen from the accompanying figure (Fig. 25).

The specimen figured below was accidentally fractured, and a little of the intervening material lost; but the two portions are represented in their natural position, and the zone of transition is fortunately preserved in the upper one. A large section prepared from the zone of transition shows its gradual character in a very perfect manner.

The micro-structure of the hornblende schist is represented in Fig 2, Plate XX., and Fig. 1, Plate XXI. The hornblende occurs in irregular grains which possess definite optical characters, but are without external

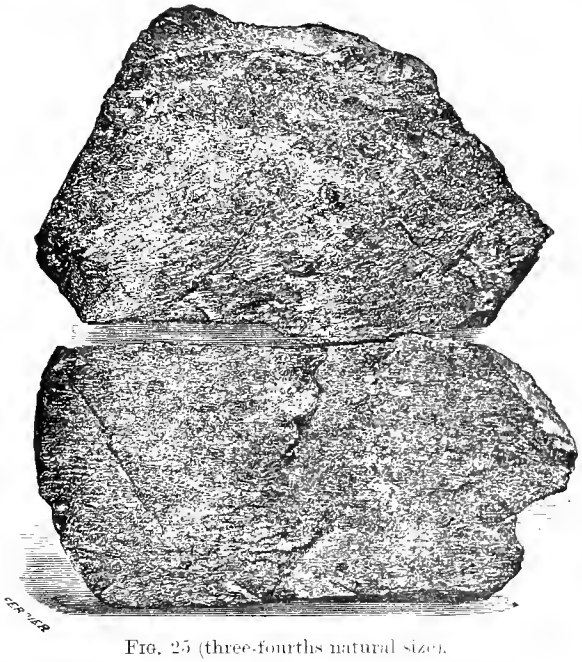

Fig. 25 (three-fourths natural size).

crystalline faces. They are usually of unequal dimensions in the different directions, and the corresponding axes lie roughly, but not rigidly parallel to each other in the rock. The longest diameter of a grain usually corresponds approximately to the vertical axis of the crystal, and lies in the plane of schistosity; the mean diameter corresponds with the orthodiagonal, and also lies roughly in the plane of schistosity; the shortest diameter corresponds with the clinodiagonal, and lies at right angles to the plane of schistosity.

The pleochroism of the hornblende is:— a = very pale greenish yellow; β = dark yellowish green; γ = rich deep green. The colourless grains are partly felspar and partly quartz. It is impossible to separate the two minerals without the use of convergent polarised light as the felspar is usually untwinned. In many cases the nature of the colourless mineral cannot be determined at all. In the less perfect schist (see Fig. 2, Plate XX.) the turbid felspars may be relics of the original mineral. The opaque iron ore may occur as grains in the schists or as long streaks lying in the

plane of schistosity. In the latter case they are frequently associated with small granules of colourless sphene.

The distribution of the foliated and non-foliated rocks in the dyke is sometimes extremely irregular and quite independent of the course of the dyke; at other times the foliation exhibits a marked tendency to curve round so as to become parallel with the margins.

There seems no reason to doubt that the change of the plagioclase-pyroxene rock to epidiorite and hornblende-schist is the result of the dynamic metamorphism which has affected the district. Where there has been no differential movement in the rock-mass we have the massive epidiorite; where differential movement has taken place the schist has been produced. Why certain portions of the dyke have retained their original characters, whilst other portions have been so completely metamorphosed, we cannot at present explain. Many dykes similar to that of Scourie doubtless occur in the Highlands of Scotland, and it is quite possible that many bands of hornblende-schist may represent dykes or sheets which have been incorporated, as it were, in the general gneissic series.

	I.	II.
SiO_2 ..	47·45 ...	49·78
TiO_2 ...	1·47	2·22
Al_2O_3 ...	14·83 ...	13·13
Fe_2O_3 ...	2·47 ...	4·35
FeO ...	14·71 ...	11·71
CaO ...	8·87 ...	8·92
MgO ...	5·00 ...	5·40
K_2O ...	·99 ...	1·05
Na_2O ...	2.97 ...	2·39
H_2O ...	1·00 ...	1·14
CO_2 ..	·36 ..	·10
	100·12	100·19
Sp. Gr. .	3.10 ...	3·11

I. Bulk analysis of the plagioclase-pyroxene rock. Dyke, Scourie (TEALL).
II. Bulk analysis of the hornblende schist (TEALL).

North of England.—The dykes in the North of England are mostly found in the districts occupied by Carboniferous rocks. One only, viz. that of Cleveland, occurs in conjunction with Secondary strata. As this dyke cuts the highest Jurassic strata in the district through which it passes, and produces marked contact alteration, there can be little doubt that it is of Tertiary age. It has been followed at intervals for a distance of ninety miles. A detailed examination of this dyke at many points along its course has established the fact that it is remarkably constant in composition; a feature which it possesses in common with all the other dykes of the North of England. It is porphyritic in texture; the porphyritic character being determined by tabular crystals of labra-

1). TEALL. Petrological Notes on some North of England Dykes. Q.J.G.S. Vol. XL. 1884, p. 209.

dorite which usually measure from 1 to 5 mm. across and occur in such numbers that three or four may generally be recognized on a square inch of surface. The ground-mass in which the porphyritic crystals lie embedded may be distinctly crystalline, finely crystalline, or compact according to the thickness of the dyke and the position from which the specimen is obtained. At the chilled margin the ground-mass is compact, but the porphyritic crystals are still recognizable. The constituents of the ground-mass are lath-shaped plagioclase, granules and crystals of augite, magnetite or ilmenite and interstitial matter. Crystals of augite are comparatively rare. When they do occur they are considerably larger than the grains and show the common forms. The interstitial matter is usually brown in colour in consequence of the presence of minute indistinct grains, fibres and flecks. In only one instance was an isotropic glass observed, and then the glass was seen to contain globulites and longulites similar to those of the Eskdale dyke. The common, brown interstitial matter is crypto-crystalline and frequently contains microlites and skeleton crystals of felspar (see Fig. 7., p. 15). The rock possesses a specific gravity of 2·77 and a silica-percentage varying from 57 to 59. It is therefore an andesitic dolerite (augite-andesite). In addition to the constituents mentioned above this rock usually contains quartz, which may be in part original. At Bolam in Durham this dyke expands laterally into a small sill or laccolite from the surface of which the Carboniferous strata have been removed by denudation. Here and also at Cockfield it has been locally altered into a light-coloured substance from which the lime, magnesia, and iron have been almost wholly and the alkalies partially removed. Incipient stages of alteration are indicated by the development of carbonates, and as a consequence of this many portions of the rock effervesce freely when treated with acid. This is a feature which may be commonly observed in basic rocks of all ages. The micro-structure of the ground-mass of this rock, near the margin where it has been cooled rapidly, offers a marked contrast to that of the central portions of the dyke. It is a veritable "mikrolithen filz," that is, a closely matted aggregate of minute felspar microlites. In this respect it differs from the rocks of the basalt-family, and resembles the typical andesites.

The Acklington Dyke, like that of Cleveland, may be followed at intervals for a very considerable distance. It is seen on the sea-coast at Bondicar, Northumberland, and may be traced from this locality into the Cheviot district. It is probably represented also in the south of Scotland At Acklington it is about 30 feet wide. The rock is distinctly crystalline and of a dark bluish grey colour, which rapidly changes to black on exposure. In mineralogical composition it differs from the Cleveland dyke merely in the absence of any conspicuous porphyritic felspars. In composition and texture it is constant throughout the entire length examined. Its specific gravity is about 2·81; that is, somewhat higher than the Cleveland Dyke. The rock is an andesitic dolerite. Although the dyke is nowhere seen in contact with any younger rocks than the Coal-measures it may be referred with great confidence to the Tertiary period.

The Cleveland, Acklington, and Eskdale Dykes are thus seen to possess the closest possible relations to each other. They are non-olivine bearing plagioclase-augite rocks, containing a certain amount of interstitial matter, and possessing a lower specific gravity and higher silica-percentage (see analyses p. 206) than normal dolerites or basalts. As already remarked they belong in all probability to one of the later phases of Tertiary volcanic activity.

We have now to refer to some other dykes occurring in the North of England, about the age of which it is necessary to speak with a considerable amount of caution.

Near the villages of Tudhoe and Hett, in Durham, a dyke of basic igneous rock occurring in the Coal-measures has been worked for road metal on an extensive scale. The course of the dyke is nearly E. and W., sometimes showing a tendency towards the E.N.E. and W.S.W. In the latter respect this dyke differs markedly from those of Cleveland and Acklington, both of which tend towards W.N.W. and E.S.E. directions; sometimes running N.W. and S.E. The rock is dark grey or bluish grey in colour and either fine or medium grained. Its specific gravity varies from 2·94 to 2·96. It is composed of plagioclase, augite, magnetite, and a very small amount of interstitial matter. The felspars belong to one generation. They are strongly acted upon by hot hydrochloric acid in a few hours, and belong therefore to a basic species. The pyroxene occurs in isolated granules and also in granular aggregates. It is pale in colour and is sometimes seen to be penetrated by the felspar. The structure is, however, in no case markedly ophitic. The iron ore in this rock appears to be magnetite, as it gives rise to brown decomposition products and is removed from the slide by hot hydrochloric acid. The interstitial matter occurs only in very small quantity. It is brown, and gives a vague reaction with crossed nicols.

About two miles to the north of Tudhoe and Hett is another dyke of similar composition, and between the two, at a depth of about 60 fathoms occurs a horizontal sheet of similar material. This sheet has been proved by mining operations to cover an area of 15 acres at least. It is associated with the Coal-measures. The rocks of the two dykes and the intrusive sheet have been described by Sir I. Lowthian Bell, and his analyses are quoted below.

The Hebburn Dyke occurs in the northern part of the county of Durham. It crosses the Tyne at Walker and enters the county of Northumberland. Its course has been traced by the numerous colliery workings in the district. At Boldon Pit the rock of the main mass of the dyke is very dark, almost black in colour, and uniformly crystalline in texture. Here and there it contains small spherical amygdaloids, measuring on the average about 1 mm. in diameter. These are occupied by calcite and quartz. The specific gravity of the unaltered rock is 2·84. Under the microscope the rock is seen to consist of felspars, pyroxene, magnetite or ilmenite, and a considerable amount of interstitial matter. The felspar sections are usually very long in proportion to their width, a feature which

characterizes most of the North of England dykes which remain to be described. The pyroxene is almost colourless and frequently occurs in good sized ophitic plates. The interstitial matter is very abundant. It is frequently rendered almost opaque by brownish granular matter. It also contains skeleton felspars, acicular microlites of felspar and grains, rods or plates of iron-ore.

The chilled margins of the dyke are formed of a compact rock which effervesces freely with acid. Under the microscope this rock is seen to be micro-porphyritic. The larger constituents are small columnar felspars, frequently having bifid or ragged terminations, pseudomorphs after a well-crystallized augite, and irregular grains of opaque iron ore. The ground-mass is a confused aggregate of extremely minute felspar microlites, specks of opacite and indistinct brownish granules. Isotropic glass may or may not be present. A considerable amount of calcite in the form of crystalline powder is scattered through the rock. The absence of well-formed augites in the central portions of the dyke coupled with their presence in the marginal portions is a fact of some importance, as apparently showing that the period of the consolidation of the augite is dependent upon physical as well as upon chemical conditions. The micro-structure of the marginal portions of the dyke is that of an augite-andesite.

The Tynemouth Dyke is exposed on the sea-coast at the base of the rock on which the Priory stands. It runs nearly East and West. The well-known Coley Hill Dyke, near Newcastle, is probably a portion of the same igneous mass. The principal feature of the Tynemouth and Coley Hill dykes is the occurrence of large porphyritic crystals, or crystalline granular aggregates, of a felspar allied to anorthite (bytownite). The analysis of these porphyritic elements is given on page 146, and a description of their general characters on page 141. The groundmass in which the porphyritic constituents are embedded is similar in all essential respects to the general mass of the Hebburn Dyke. The distribution of the porphyritic constituents throughout the mass of the dyke is somewhat irregular. Some portions are almost entirely free from them, and it is remarkable that these portions are usually very rich in small spherical amygdaloids, now mainly occupied by calcite.

A few miles north of Tynemouth, near the villages of Seaton and Hartley, several dykes are known. They run approximately parallel to each other in a direction somewhat north of west and south of east. Everywhere they present the same general characters. The unaltered rock is dark, in some cases almost black in colour, and finely crystalline in texture. Porphyritic elements are rare, but now and then crystals of felspar, similar to those of the Tynemouth Dyke, may be recognized. In some specimens the small spherical amygdaloids may be detected. Alteration at the surface gives rise to brown colours, but in the coal-pits these are never observed, the large amount of carbonaceous matter causing the water to act as a reducing instead of an oxidizing agent.

The decomposed rock in the pits is in the condition of "white trap." (1)

Under the microscope one recognizes long, narrow, lath-shaped sections of plagioclase, irregular grains and plates of a colourless pyroxene, and a certain amount of interstitial matter rendered more or less opaque by crystals, rods and grains of iron-ore, brownish globulites, and other bodies. Sometimes the interstitial matter is a brown isotropic glass; at other times it is a colourless glass crowded with minute brownish globulites; in most cases, however, it is difficult to define its precise character in consequence of its opacity even in very thin sections.

As a general rule the Hebburn, Tynemouth, Seaton, and Hartley dykes are free from olivine, or contain it only in very small quantities. We have now to notice a dyke, evidently belonging to the same series, in which olivine appears to be tolerably abundant. It occurs near the railway viaduct at Morpeth. The rock of this dyke is somewhat blacker and more coarsely crystalline than that of the dykes hitherto described; it is also denser, its specific gravity lying between 2·88 and 2·89. Crystals and crystalline granular aggregates of felspar occur as porphyritic elements; but as they do not differ markedly in size from the larger felspars of the groundmass, they are not so easily recognized in the hand specimen as in the thin section. Olivine occurs both fresh and in the form of serpentinous pseudomorphs. The other constituents are similar in their character and relations to those of the Hebburn and Tynemouth dykes. The augite is perhaps a little more abundant and more prone to assume the ophitic form.

Two dykes, presenting a type of structure somewhat different from that of any of those previously described, are exposed on the east side of the Tarret, near High Green, a farm-house about five miles N.N.W. of Bellingham. The constituents of these dykes, as seen under the microscope, are lath-shaped felspars, not very long in proportion to their width, a pale brown pyroxene, occurring in grains, ophitic plates and granular aggregates, large irregular plates of magnetic iron ore and apatite. A very small amount of pale brown interstitial matter may be detected. In the more northerly dyke two generations of felspar occur. The felspars of the first generation are, however, few in number, and by no means conspicuous. The specific gravity of the rock of these two dykes lies between 2·9 and 2·93. The differences between the High Green dykes and those of Tynemouth and Hebburn depend upon—(1) the amount of interstitial matter; (2) the form of the felspars; (3) the form of the opaque iron ores; (4) the specific gravity, and (5) the chemical composition. In all these respects the High Green dykes approach the Whin Sill which remains to be described.

A very interesting feature illustrating the chemical processes involved in the decomposition of basic igneous rocks may be seen at the northern

(1) South Staffordshire Coal Field. JUKES, 2nd Edit,, p. 118.

margin of the more southerly of the two High Green dykes. The decomposed rock shows a cellular structure, evidently connected with its mode of jointing. The walls of the cells are formed of a deep brown, comparatively hard substance, evidently rich in ferric oxide; while the cells themselves are filled with a white or cream coloured friable substance resembling kaolin. The following analyses by Mr. STEAD, of Middlesborough, show the composition (I.) of the comparatively unaltered rock (II.) of the cell walls, and (III.) of the cell contents:—

	I.	II.	III.
SiO_2 ...	53·70	43·50	66 20
Al_2O_3 ...	18·21	14·61	23·92
Fe_2O_3 ...	10·64	31·14	0·78
CaO ...	6·66	0·44	0·95
MgO ...	5·24	0·11	0·33
K_2O ...	0·99	0·09	0·04
Na_2O ...	2·65	0·26	0·57
H_2O ...	1·55	9·50	7·00
CO_2 ...	—	—	tr.
	99·64	99·65	99·79

On comparing these analyses with each other we see that the effect of the alteration has been to remove the alkalies and alkaline earths, to introduce water and to concentrate the iron along the joint planes. It is not difficult to trace the probable steps by which these results have been brought about. In the first place, the silicates would be decomposed by the action of water charged with carbonic acid and the carbonates of lime, magnesia, and iron thus formed would be in part held in solution by an excess of carbonic acid. This solution would come in contact with oxygen along the joint planes and hydrated ferric oxide would be precipitated. Diffusion would tend to cause the carbonates held in solution in the interior of the cells to move outwards, and thus fresh portions of the ferrous carbonate would be brought under the influence of oxygen, obtaining access by means of the joint planes, and a further precipitation of ferric oxide would take place. This process would go on until the whole of the iron had been concentrated in the neighbourhood of the joint planes. The carbonates of lime, magnesia, and the alkalies would of course also be removed from the interior portions of the cells; but, as there would be no chemical action tending to precipitate the bases of these salts at the joint planes, they would be wholly removed from the rock. Here then we witness the result of an interesting chemical operation iron is separated from calcium, magnesium and the alkalies by the action of oxygen on a solution of the carbonates; iron is precipitated as ferric oxide, while the other substances remain in solution.

In concluding this account of the dykes of the North of England

we have to note that those which have been examined fall into three groups :—

I. The dykes of Cleveland and Acklington.
II. The dykes of Hebburn, Tynemouth, Seaton, and Hartley.
III. The dykes of Hett and High Green.

Those of the first group are of Tertiary age; those of the second group are of unknown age; those of the third group resemble the Whin Sill in composition and specific gravity, and are, in all probability of pre-Tertiary age.

ANALYSES OF NORTH-OF-ENGLAND DYKES.

	I.	II.	III.	IV.
SiO_2	57·57	58·07	57·80	58·30
Al_2O_3	14·25	13·22	16·18	16·14
Fe_2O_3	6·04	10·10	10·07	4·76
FeO	3·95			4·50
MnO	0·27	—	—	—
CaO	6·87	7·04	6·18	10·96
MgO	4·24	4·46	4·68	2.68
K_2O	1·08	1·58	0·77	0.94
Na_2O	2·98	2·59	2.38	1·74
S	0·19	—	—	—
CO_2	0·30	—	—	—
P_2O_5	0·15	—	—	—
TiO_2	tr.	—	—	—
H_2O	1·25	1·50	1·70	—
	99·14	98·56	99·76	100 02
Sp. Gr.	2.77	—	2·81	2·84

	V.	VI.	VII.	VIII.
SiO_2	51·20	51·35	51·90	53·70
Al_2O_3	20·03	17·61	15·46	18·21
Fe_2O_3, FeO	7·57	12·04	12·87	10·64
MnO	—	—	—	—
CaO	10.52	9·65	13·80	6·66
MgO	6·75	5·68	4·02	5·24
K_2O	0·51	1·40	1·21	0·99
Na_2O	1·71	0·56	0·48	2·65
S	—	—	—	—
CO_2	—	1·53	1·02	—
P_2O_5	—	—	—	—
TiO_2	—	—	—	—
H_2O	1·70	—	—	1·55
	99·99	99·82	100·76	99·64
Sp. Gr.	2·88	2·95	2·96	2·92

I. Cleveland Dyke, Great Ayton, Yorkshire (STOCK).

II. Armathwaite Dyke, Armathwaite, Cumberland (STOCK). The Armathwaite Dyke is a continuation of the Cleveland Dyke. The two specimens analysed by Mr. STOCK were taken from points about sixty miles apart.

III. Acklington Dyke, Acklington, Northumberland (STEAD).

IV. Tynemouth Dyke, Tynemouth, Northumberland (STEAD).

V. Morpeth Dyke, Morpeth, Northumberland (STEAD).

VI. Hett Dyke (BELL). (1)

VII. Intrusive sheet in Coal-measures, near Hett Dyke (BELL).

VIII. South Dyke, High Green, near Bellingham, Northumberland (STEAD).

The most important mass of basic igneous rock in the north of England is that known as the Whin Sill. The relations of this mass to the strata of Lower Carboniferous age have given rise to some discussion but it is now generally recognized as being intrusive.(2) It is exposed as an inlier in Teesdale, and may be followed up the valley for a considerable distance. It reappears in the Cross Fell escarpment in Cumberland where its intrusive character is easily recognized, and it may be traced thence with slight interruptions across the county of Northumberland to the sea coast at Dunstanburgh, following in a general way the strike of the beds with which it is associated. As the strike bends round to the N.W. in the northern portion of Northumberland, the Whin Sill reappears on the coast at Bamborough, and may be traced from this point to Kyloe, where it is last seen. The distance from the most southerly point in the Cross Fell escarpment where the Whin Sill is exposed to Dunstanburgh is sixty or seventy miles, so that the total mass of the Whin Sill must be enormous. It forms an intrusive sheet which varies in thickness from 20 to 150 feet. Its average thickness in Northumberland is about 80 or 100 feet, according to Professor LEBOUR. The date of its formation is not known with precision. It must be posterior to the Lower Carboniferous period and anterior to the disturbances which have affected the district. This seems to imply that it is post-Carboniferous and pre-Permian.

The prevailing type of rock is a distinctly crystalline (medium grained) mixture of plagioclase, pyroxene, and titaniferous iron ore. Olivine does not appear to occur, but its place is taken in certain varieties by a rhombic pyroxene. Where the rock bulks very largely, as at Tyne Head and Cauldron Snout, we find irregular masses of a coarsely crystalline variety. In these the augite is frequently developed in the form of long, bladed crystals. The individuals are somewhat irregular in outline, but the dominant forms are easily made out to be the two vertical pinacoids (100) and (010), the prismatic faces being simply represented by truncations. Each individual is, as a rule, twinned according to the ordinary law, (see Fig. 21, page 157), and *several individuals are frequently seen to be arranged parallel to each other* in the rock. The direction in which the crystals are elongated is that of

(1) Proc. Roy. Soc., 1875, p. 543.

(2) Messrs. TOPLEY & LEBOUR. On the intrusive character of the Whin Sill of Northumberland. Q. J. G. S., Vol. XXXIII., p. 406,, 1877.

the vertical axis. Another special feature of these crystals is the presence of diallagic lamination parallel to the basal plane. This striation is best exhibited in clino-pinacoidal sections, when it is seen to make an angle of about 74° with the vertical axis and, in the case of a simply twinned crystal, to produce a kind of herring bone lineation with reference to the trace of the face of composition (100).

The coarser varieties of the Whin Sill also frequently contain micro-pegmatite which plays the rôle of interstitial matter exactly as it does in the more acid gabbros of Carrock Fell. Brown hornblende sometimes occurs as an accessory constituent. It is found intergrown with the augite in such a way that the plane of symmetry is common to the two minerals.

The general structure of the normal rock may be described as sub-ophitic. The augite which is pale in colour occurs for the most part in granular aggregates rather than as large plates exhibiting uniform extinction over wide areas. Nevertheless, it is frequently penetrated by the lath-shaped felspars in such a way as to show that it is, on the whole, of later date. In other words there is a marked approach to the ophitic character. Compared, however, with the typical ophitic olivine-dolerites of Tertiary and Carboniferous age and with the ophitic non-olivine bearing dolerites (diabases) of Lower Palæozoic age, the ophitic character is seen to be very imperfectly developed.

The felspars belong, on the whole, to one generation. The examination of a large series of microscopic slides, however, reveals the occasional presence of felspars which are earlier in date than those of the main mass of the rock. These are never known to occur in such numbers as to give a porphyritic character to the rock.

The iron-ore is both magnetic and titaniferous. It is, in all probability, an intergrowth of magnetite and ilmenite.

The rhombic pyroxene occurs by itself and also intergrown with augite. It is not present in all sections, at the same time it is by no means a rare constituent. It shows faint pleochroism of the characteristic type and is generally more or less altered to a green fibrous substance (bastite).

Brown mica occurs occasionally as an accessory constituent. Chlorite and pyrite are found among the alteration products.

At its junction with the sedimentary rocks the Whin Sill becomes finely crystalline and even compact. The compact variety shows in thin section a micro-porphyritic texture. Small, more or less lath-shaped sections of felspar lie embedded in a ground-mass composed of minute and evenly distributed specks of iron oxide and extremely small felspar microlites. In the thinnest preparations these microlites are superposed on each other so that it is impossible to speak with certainty as to the presence or absence of interstitial matter. There is the closest possible resemblance between the ground-mass of the compact rock and that of many andesites. The finely crystalline rock which occurs a foot or two from the junction presents a very different type of micro-structure. It appears under the microscope at first glance to be holocrystalline and to consist

of augite granules, lath-shaped sections of felspar, and grains of iron ore. On closer examination an extremely minute quantity of interstitial matter may generally be detected between some of the felspar sections.

In its composition and structure the rock of the Whin Sill is remarkably uniform throughout the entire area. The specific gravity is also fairly constant. It varies from about 2·9 to 2·98. (See Fig. 2, Plate XIII.).

ANALYSES OF THE WHIN SILL.

	I.	II.
SiO_2	51·22	50·71
TiO_2	2·42	1·92
Al_2O_3	14·06	14·78
Fe_2O_3	4·32	3.52
FeO	8·73	8·95
MnO	0·16	0·31
CaO	8.33	8·21
MgO	4·42	5·90
K_2O	1·25	1·39
Na_2O	2.55	2·76
H_2O	1·28	1·78
CO_2	0·19	0·25
P_2O_5	0·25	—
FeS_2	0·49	—
	99·67	100·48

I. Whin Sill. Cauldron Snout, Durham (TEALL). (1)
II. Whin Sill. Crags near the Roman Station of Bourgovicus, Northumberland (TEALL).

Midland Counties.—Contemporaneous volcanic products of basic composition occur at two horizons in the Carboniferous Limestone of Derbyshire. They are well exposed in Tideswell Dale, Miller's Dale, in the neighbourhood of Matlock, and in the Ashover Valley. Intrusive rocks occur here and there, and these may be referred with considerable confidence to the same general period. The local name for the igneous rocks of Derbyshire is "toadstone." They are very often amygdaloidal and so highly decomposed throughout their entire mass that it is impossible to make out their original characters. These decomposed amygdaloidal varieties would be termed *melaphyre*, or *diabase-mandelstein* on the Continent. Similar decomposed masses occur abundantly in the Midland valley of Scotland and are well exposed on the Island of Inchkeith. In Derbyshire they may be seen in Miller's Dale by the roadside.

The rock of Tideswell Dale is comparatively fresh. It is exposed in an old marble quarry on the right-hand side of the road leading up the valley from Miller's Dale to the village of Tideswell. It is a distinctly crystalline rock containing large olivines, now for the most

(1) Q. J. G. S., Vol. XL. (1884), p 654.

part changed to serpentine, lath-shaped plagioclase, augite which may occur either in the form of grains or ophitic plates (see Figs. 1 and 2 Plate IX.), and magnetite or ilmenite. The rock is therefore an olivine-dolerite which shows in certain parts the ophitic type of structure, in others the "type with granular augites." Indications of fluxion structure may be seen in the latter. The relations between these two types of structure have been already considered in describing the Tertiary dolerites of the west of Scotland. It is interesting to note that the Tideswell Carboniferous rock is exactly similar to the Tertiary olivine-dolerites of Tobermory, Portree, and Portrush, both as regards structure and composition. The specific gravity of the least altered specimens of the Tideswell Dale rock is 2·91.

In Cavedale, near Castleton, a single column of a black basaltic rock is exposed. It is finely crystalline and possesses a specific gravity of 2·76. Under the microscope it is seen to be composed of lath-shaped plagioclase, colourless augite-grains often more or less altered, rods of magnetite and a considerable quantity of interstitial matter crowded with minute grains and rods of magnetite and often changed to a green alteration product. Felspar is more abundant than augite. Notwithstanding the thoroughly basaltic aspect of this rock, it is evidently not a true basic rock. It belongs to the border line between the rocks of basic and those of intermediate composition, and is thus allied to the andesitic dolerites (augite-andesites).[1]

Mr. ALLPORT has described the rocks from the neighbourhood of Matlock.[2] They form two bands in the Carboniferous limestone and may be examined on the railway near the entrance to the tunnel through the High Tor, as well as on the opposite side of the valley at the Heights of Abraham. A specimen from the upper band at the latter locality is a typical olivine-dolerite of the Tideswell Dale type. A specimen from the lower band contains a considerable amount of interstitial matter rendered opaque, except in the very thinnest sections, by minute grains of magnetite. These rocks contain amygdaloidal or pseudo-amygdaloidal cavities filled with calcite and chlorite.

Various exposures of basic igneous rock occur in association with the Carboniferous strata of the Midland Counties, in Leicestershire, Staffordshire, and Shropshire, The largest of these is that of the Rowley Hills, near Birmingham. These hills have a capping of dolerite resting on Coal-Measures, and extending over "an irregular space two miles long by more than a mile in width, at one part."[3] Other exposures in the South Staffordshire Coal Field occur at Barrow Hill, two miles west of Dudley, and at Pouk Hill, near Walsall. Intrusive sheets and veins of igneous rock are also constantly met with in the course of the colliery workings. Where they come in contact with the coal they have been frequently converted into "white trap." In most cases, if not in all, the igneous rocks are in-

(1) Figs. 1 and 2, Plate XIV., may be taken to represent the Cave Dale rock.

(2) Q. J. G. S., Vol. XXX., 1874, p. 551.

(3) On the South Staffordshire Coal Field. Memoirs of the Geol. Survey, 1857.

trusive, and therefore some difficulty is experienced in determining their age. The entire absence of similar rocks in the strata overlying the Coal-Measures (New Red Sandstone), and the fact that they have been affected by the same dislocations as the Coal Measures, led Professor JUKES to refer them either to the later portion of the Carboniferous period or to the immediately succeeding period. In any case they seem to have been formed before the New Red Sandstone period. The basic igneous rocks associated with the Coal-Measures of Leicestershire and Shropshire doubtless belong to the same period.

The petrographical characters of the rocks have been described by Mr. ALLPORT.[1] Mr. WALLER has added some very interesting facts with regard to the contemporaneous veins in the Rowley Rag mass.[2] To a certain extent these rocks must be regarded as classical in the history of petrography as they furnished to Mr. ALLPORT absolute evidence that rocks identical in structure and composition with Tertiary dolerites have been produced in very early geological times.

The normal rock of Pouk Hill is a typical ophitic olivine dolerite. "A specimen from the centre of a column near the middle of the large quarry exhibits in a thin slice, the whole of the constituents in a remarkably fresh condition. The plagioclase occurs in the usual long prisms and is distinctly striated. The augite is in grains of irregular shape, and is frequently penetrated by the felspar; its colour varies from yellowish to purplish brown; and some of it is slightly dichroic. Olivine is extremely abundant, and is often nearly or even quite unaltered; other crystals, however, are partially converted into a green substance round the edges and along the sides of fissures; a little of the green substance has also found its way here and there among the felspar prisms. The never-failing magnetite occurs in moderate quantity; and there are a few needles of apatite, together with an occasional small patch of amorphous glass. The rock is quite undistinguishable from a Tertiary dolerite, either in mineralogical composition or state of preservation."[3] The microscopic structure of this rock is essentially similar to that of the rock from Tobermory represented in Fig. 1, Plate X. The principal difference lies in the colour of the augite, which is much more pronounced in the case of the Pouk Hill rock. The sheet of dolerite overlying the Coal-Measures and underlying the Trias met with in the course of colliery workings at Whitwick, in Leicestershire, is similar in structure and composition to the rock from Pouk Hill above described.

In addition to the ophitic olivine-dolerite there occurs also at Pouk Hill, near the bottom of the cutting, a rock of micro-porphyritic structure. Comparatively large crystals of felspar and olivine (pseudomorphs) lie embedded in a compact matrix "consisting of minute grains or crystals of felspar, augite and magnetite."

(1) G. M., 1870, and Q. J. G. S., Vol. XXX. (1874), p. 529.
(2) Midland Naturalist (1885), Vol. VIII., p. 261.
(3) Mr. ALLPORT, *loc. cit.*

The rock of the Rowley Hills presents some interesting points of difference when compared with that of Pouk Hill. It is, as a rule, somewhat finer in grain, but contains local patches which are extremely coarse, and in which the augite exhibits a tendency to run out into large, bladed crystals. It contains also red and grey contemporaneous veins which differ in composition from the main mass of the rock. In this section the constituents of the Rowley mass are seen to be the same as those of Pouk Hill; but the augite and the felspar do not exhibit the same relations. The augite in the Rowley rock frequently shows more or less definite form and crystals of this mineral are sometimes seen to lie in the felspar. At the same time there is evidence that the whole of the augite did not separate before the felspar, for a lath-shaped section of the latter mineral may sometimes be seen to penetrate a grain or imperfect crystal of augite. In some of the coarsely crystalline patches Mr. ALLPORT observed a remarkable intergrowth of felspar and augite (see Fig. 2 Plate XXIII.). The two minerals form globular aggregations and, though intimately intermingled, each possesses uniform optic properties over large areas. This is an illustration of the ocellar structure of FISCHER, the centric structure of BECKE, and the micro-pegmatitic structure of French authors.

It is interesting to note that in South Staffordshire we have illustrations (1) of dolerites in which the felspar has preceded the augite, (2) of dolerites in which the two minerals have crystallized simultaneously, and (3) of dolerites in which the felspar has succeeded the augite. Ilmenite in good-sized hexagonal tables is found in the Rowley rock, and is sometimes collected in considerable abundance in special localities. The olivine of the Rowley rock is often distinctly coloured in thin section and evidently belongs to a variety extremely rich in iron. It passes over into deep green alteration products. The observations of Mr. ALLPORT and Mr. WALLER show that the mass is by no means uniform in structure or composition. In some varieties olivine appears to be absent, in others it is very abundant. The rock is usually granular; but micro-porphyritic varieties are sometimes found. In these the ground-mass is formed of very small crystals of felspar and augite with a considerable amount of magnetite.

The grey contemporaneous veins consist of perfectly fresh felspar, green augite and interstitial matter which is partly at any rate in the condition of glass. The felspars are seen under the microscope to be either simple individuals or binary twins. The striation so common in plagioclase is absent. Many of the binary twins extinguish simultaneously when the trace of the face of composition lies parallel with one of the vibration planes. Orthoclase must therefore be present. The interstitial matter sometimes contains slender felspar-microlites which are often beautifully curved. The green colour of the augite is interesting as it is in marked contrast with the brown colour of the normal augite of the rock and similar to that of certain acid rocks (Mull granophyres), and of certain rocks rich in alkalies.

The following analyses illustrate the composition of the Rowley dolerite and of the contemporaneous veins :—

	I.	II.	III.
SiO_2 ...	49·860	48·8	58·3
TiO_2 ...	1·330	not est.	—
Al_2O_3 ...	12·750	18·1	17·9
Fe_2O_3 ...	3·360	3·5	2·5
FeO ...	11·380	7·2	3·0
MnO ...	not est.	not est.	—
CaO ...	8·710	8·4	2·1
MgO ...	4·395	4·9	1·9
Na_2O ...	5·250	3·7	5·2
K_2O ...	0·570	1·9	5·9
P_2O_5	0·580	—	—
H_2O ...	2·560	3·6 (Ig.)	2·7 (Ig.)
	100·745	100·1	99·5
Sp. Gr. ...	2·907	2·79	2·58

I. Dolerite, Rowley. Analysis by Mr. Henry. Quoted from the Geological Survey Memoir on the South Staffordshire Coal Field. 1859, p. 117.

II. Dolerite, Hailstone Hill, Rowley. Mr. Waller. Midland Naturalist, Vol. VIII., p. 265. The rock contains about 2 p. c. of titanic acid which was not estimated in this analysis.

III. Contemporaneous vein (grey) in dolerite from Hailstone Hill. Mr. Waller, *loc. cit.*

It is interesting to note that the contemporaneous vein contains more silica, less iron, lime and magnesia, more alkali, and relatively more potash than the main mass of the rock (see *ante* page 42).

The basic igneous rocks found beneath the surface in the collieries of the South Staffordshire district appear to be in most cases more altered than those just described. When found away from the coal they are usually green in colour owing to the presence of chlorite, chlorophæite, or other green decomposition products. Zeolites are often abundant. In the neighbourhood of the coal they become light coloured or even white (white trap). Apart from the alteration to which they have been subjected, they bear a close relation to the rocks of the Rowley Hills and the Pouk Hill. Thus a rock from a colliery at Deepmore, two miles N.W. of Walsall, was originally an ophitic olivine-dolerite. In the white trap the alteration has been so complete as to have destroyed altogether the original minerals; their forms only having been preserved. The white colour is, of course, due to the fact that the carbonaceous matter of the coal has prevented the oxidation of the iron.

A very interesting type of rock occurs at Tansley Hill, near Dudley. It is a compact rock (basalt) of micro-porphyritic texture. The porphyritic constituents are felspar and occasionally olivine, but they can only be recognized under the microscope. The ground-mass which makes up by far the greater portion of the rock is an aggregate of extremely minute augite crystals magnetite crystals and rods (? ilmenite), and felspar. The felspar mostly gives lath-shaped sections the outlines of which are more or less indistinct (see Fig 2, Plate XXIV.). What is important about this rock is

that the felspar plays the rôle of ground-mass. A somewhat similar rock occurs in Swinnerton Park, eight miles N.E. of Stafford. This rock, however, contains less felspar and is richer in olivine, much of which is perfectly unaltered. It forms, according to Mr. ALLPORT, a part of a mass of dolerite of somewhat variable texture.

If we take a general view of the dolerites of the Midland Counties we note that they are characterized by the presence of olivine, often rich in iron, and by the frequent occurrence of deeply-coloured augites. In both these respects they differ markedly from the dolerites of the North of England, and resemble some of those occurring in the Midland Valley of Scotland and in the Island of Arran. The normal rock of Pouk Hill is substantially identical with many Tertiary dolerites occurring in the north of Ireland, west of Scotland and Iceland.

North Wales.—The counties of Merionethshire and Caernarvonshire contain immense masses of igneous material. The contemporaneous volcanic rocks of Merionethshire form a large portion of the mountain ranges of Cader Idris, the Arans, the Arenigs, the Manods and Moelwyn. They consist for the most part of acid material and belong to the Arenig period. The corresponding rocks of Caernarvonshire form a large portion of the Snowdonian group of mountains and belong to a later period, viz., the Middle Bala of SEDGWICK. In both areas we find numerous exposures of basic igneous rocks. These are, however, for the most part intrusive and not interbedded. The most important exposure of contemporaneous volcanic products of basic composition occurs in the neighbourhood of Rhobell Fawr, five or six miles N.N.E. of Dolgelli. Here we find basic tuffs and breccias containing well-preserved zonal augites, zonal plagioclase, brown hornblende, lapilli, and a matrix which doubtless represents the finer fragmental volcanic material. The alteration to which these rocks have been subjected has given rise to the development of chlorite, epidote and other alteration products. These rocks are associated with typical ophitic diabases. The massive igneous rocks occasionally, though rarely, have a basaltic rather than a doleritic structure, and so far as petrographical characters are concerned these varieties may well be contemporaneous lava flows. Professor RAMSAY however, states[1] that "in no single case in Merionethshire is there any line of greenstone that can be proved to have flowed across a land surface or sea bottom. There may be some difficult cases, and there are many in which a cursory examination would recognize no difference between their mode of occurrence and that of the felspathic lavas, but a thorough acquaintance with the igneous rocks of Merionethshire will show that in no single instance is it safe to include any line of greenstone in the list of lava currents, and most of them may be safely dismissed from that category."

There can be no doubt, therefore, that in the vast majority of cases the greenstones are intrusive. They occur as sheets running more or less parallel with the bedding, and sometimes reaching a thickness of several

(1) The Geology of North Wales. Survey Memoirs, Vol. III., 2nd Edit., 1881, p. 99.

hundred feet and also as vertical, or nearly vertical, dykes. Professor RAMSAY says: "It is not to be supposed that the greenstones are in this region all precisely of one date, but for many reasons it may be considered certain that the majority of those *that lie more or less between the beds* were injected in Lower Silurian [Ordovician] times, in which case they were of prior date to the disturbances of the rocks, and consequently to the development of the cleavage of the country. This, however, is not invariable, for it will be shown that in Caernarvonshire some of the common *vertical* dykes include fragments of cleaved slate. These, I believe, were injected at a much later date." (1)

The number of separate exposures of "greenstone" in Merionethshire and Caernarvonshire must be reckoned by hundreds, if not thousands. Up to the present time the rocks have not received much attention at the hands of modern petrographers. Mr. TAWNEY has given us an account of some of those occurring in the Lleyn Peninsula of Caernarvonshire and his papers (2) contain almost all that is known as to the precise composition of the augitic greenstones of North Wales. Many specimens and sections of the rocks from various localities exist in public and private collections. The following remarks are based on the examination of some of these and on Mr. TAWNEY'S published observations. The older observers regarded the "greenstones" as being largely composed of hornblende. This is now known not to be the case, at least to anything like the extent formerly supposed. Hornblendic greenstones (diorites) occur in the Lleyn Peninsula and Anglesea, and probably also in Merionethshire, but they are certainly subordinate to the augitic greenstones (diabases).

If a collection of the augitic greenstones of North Wales be placed side by side with a collection of Carboniferous or Tertiary dolerites, little difficulty will be found in distinguishing them. Here and there individual specimens may be seen to be identical, but taken as a whole each collection will have its distinctive characters. Thus chlorite is an almost constant feature in the greenstones; hence their name. Olivine as a rule is unrepresented either in the fresh or altered condition. The plagioclase is generally turbid and sometimes almost opaque in consequence of alteration. The ragged plates of ilmenite are generally more or less changed to leucoxene. It must indeed be confessed that none of these characters taken by itself is distinctive of the Lower Palæozoic greenstones, and yet taken together they give a general aspect to any extensive collection of these rocks by which it may be distinguished from a similarly extensive collection of British Tertiary or Carboniferous dolerites.

There is one special type of rock which is very widely distributed in Merionethshire and Caernarvonshire. It is a medium grained, dark

(1) A specimen in the ALLPORT collection in the British Museum from the neighbourhood of the South Stack Lighthouse, Holyhead, Anglesea, is a wonderfully fresh ophitic olivine-dolerite. In its composition and state of preservation it differs so markedly from the "greenstones," and approaches so closely many of the Carboniferous and Tertiary dolerites that one is inclined to regard it as a rock of much later date.

(2) Woodwardian Laboratory Notes, G.M., 1880, pp. 207 and 452; *Ibid.*, 1882, p. 548 *Ibid.*, 1883, pp. 17 and 65.

greenish grey, granular rock, having a specific gravity of about 2.95. Not unfrequently it shows lustre-mottling. Under the microscope it is seen to have consisted originally of large irregular ophitic masses of augite, columnar (lath-shaped in section) plagioclase, and irregular plates of ilmenite. The lustre-mottling is due to the fact that the ophitic masses of augite are penetrated by felspar. The ilmenite is almost always more or less changed to leucoxene, which is in some cases transparent and possesses the refraction and double refraction of sphene. The felspars are cloudy and frequently contain spots and patches which appear snow-white by reflected light and opaque or nearly so by transmitted light. The general absence of olivine from these rocks is an important and characteristic feature. The ophitic dolerites of Carboniferous and Tertiary age generally contain this mineral. That these rocks are thoroughly basic in composition, notwithstanding the absence of olivine, is shown by their high specific gravity. They are, therefore, not allied to the andesites either in chemical composition or texture. Good illustrations of this type may be seen in Cwm Orthin, near Ffestiniog; at Y-Gesell, Moel-y-Gest and Garth near Portmadoc; at the Gimlet rock, (Careg-y-rimbill), near Pwllheli; at Porth Dinlleyn and other places in the Lleyn Peninsula; near the summit of Rhobell Fawr, six miles N.N.E. of Dolgelly; and at several points in the immediate neighbourhood of Dolgelly. These rocks are perfectly typical ophitic diabases.

It has already been stated that the intrusive sheets have been affected by the forces which have folded and faulted the sedimentary rocks. As a consequence of this we find that the diabases occasionally become schistose. There is no evidence at present that in any part of North Wales this action has gone on to such an extent as to have converted large masses of diabase into schistose rocks; but that schists have been developed locally in connection with the faulting of the diabase is certainly proved. The point is one of some importance, because it will be shown later on that a similar action has taken place in the West of England on a more extended scale.

A good illustration of the local development of schist from diabase may be seen in the quarry at Garth, near Portmadoc. The massive diabase is traversed by a fault. In the neighbourhood of the fault it has been converted into a fissile chloritic schist. The normal diabase belongs to the type already described. Very little of the augite has escaped alteration. It is now mostly represented by aggregates of chlorite which give under crossed nicols the pale bluish shimmering light so characteristic of this mineral. The chloritic aggregates are often seen to be penetrated by the lath-shaped plagioclase exactly in the same way as the original augite. A good deal of calcite dust is scattered through the rock and quartz grains, probably of secondary origin, are also present. The passage of the massive rock into the schist is accompanied, as one would naturally expect, by the gradual obliteration of the distinctive micro-structure of the original rock. The chlorite-aggregates are still recognizable in the most perfect schist, but they occur as flat ragged lenticles, their broadest sections lying in the plane

of schistosity. The ragged plates of ilmenite are deformed in the same manner, but not to the same extent. The lath-shaped plagioclase has completely disappeared. Its place is taken by micro- or crypto-crystalline aggregates of a perfectly colourless substance having the refraction and double-refraction of quartz or felspar, minute ragged scales of a colourless mineral with high double refractive power, and small prisms of a mineral with high refraction, low double refraction, and straight extinction (zoisite). The constituents of these aggregates are, however, so small and their forms so indistinct that it is extremely difficult to identify them with any degree of certainty. The occurrence of a felspathic matrix in chlorite-schist associated with diorite [? epidiorite] at Dobschau, in Hungary, has been described by NAGY. The felspar gave a strong soda-flame.(1)

The development of secondary hornblende has not been observed as yet in any considerable number of cases in the diabases of North Wales. This is an interesting point, because it is a very common feature in the West of England. Cases, however, do occur in North Wales. Thus at Mynydd Gader, between Cader Idris and Dolgelly, and other places in the same neighbourhood, a green fibrous hornblende sometimes replaces the augite of the greenstones. This is probably secondary and the rock in which it occurs may be termed epidiorite.

One interesting feature, frequently observed in connection with the larger intrusive sheets of diabase, is the marked contact alteration which they produce both above and below. This is frequently referred to by Professor RAMSAY in his description of the geology of North Wales. Thus, speaking of the distinctly crystalline greenstones, (diabases), he says: "Finer examples still occur on the cliffs that partly bound the secluded tarns of Llyn-llagi and Llyn-adar (between three and four miles east of Beddgelert), where the slate in contact with them is altered into a spotted porcelanic substance, such as is sometimes termed 'snake-stone.' This is frequently the case with slates that lie close to the greenstones of Caernarvonshire, and in such circumstances they are often quarried for honestones . . . . Good examples of greenstone and its effects may be seen on Moel-dannogen and at Bwlch-y-gerddinen, on the road from Ffestiniog to Dolwyddelan. The rock is an ordinary greenstone . . . . and largely crystalline, and the slates, both above and below the mass, are porcelanised, flaky, and speckled like 'snake stones.' Some slaty included fragments are also speckled, and others, which like these have been caught up and included in the greenstone during its intrusion have the appearance of felspathic trap [adinole]. The slates all round are highly cleaved, with the exception of the bands in the immediate neighbourhood of the greenstone. This greenstone, like others of its class, was intruded into and altered the slates before those disturbances took place that heaved and contorted the strata into their present inclined positions, and also produced the cleavage; and

(1) N. J. Ref., 1882, I., 236.

it is clear that the altered porcelanic character of the rocks in contact with the greenstone prevented their being cleaved."[1]

Again, referring to the slates altered by greenstone in the neighbourhood of Llyn Cwlyd, the same author says: "These porcelanites weather white, like the felspathic rocks, and I found it no easy matter to separate the two while mapping the country between Pen-uchaf-y-Gwaith, Llyn Cawlyd, and Capel Curig."[2] Good illustrations of the contact metamorphism of diabase may be studied in the neighbourhood of Tremadoc. The great mass of intrusive rock which forms Y.-Gesell has markedly affected the strata with which it comes in contact.[3] The dominant type of metamorphic rock is a light, grey, speckled mass often showing marked schistosity. The speckling is due to minute spots readily distinguishable with a hand lens. These spots lie in a light coloured ground-mass. In a thin section they are much less marked when viewed with ordinary light, than they are in the rock-mass. Under crossed nicols, however, they become apparent, owing to the fact that they are much darker in all positions of the stage than the general mass of the rock. The small size of the individual constituents renders it impossible to define the composition of this rock with any degree of precision. Scales of chlorite lying with their flat surfaces parallel with the planes of schistosity can be distinctly recognized; also scales of a more vividly polarizing micaceous mineral, probably sericite, aggregates of irregular grains having the refraction and double refraction of quartz and felspar. The vividly polarizing mica is much less abundant in the spots than in the general mass of the rock. The darkness of the spots under crossed nicols seems to suggest the presence of an isotropic substance. This rock answers to the spilosite of ZINCKEN, and the Hartz geologists.[4]

A typical spilosite, according to LOSSEN, consists of:—

(1) An isotropic substance forming a kind of base in which the other constituents are embedded.

(2) Very numerous and extremely minute scales of a micaceous mineral which, together with the isotropic substance, make up the main mass of the rock. These lie for the most part with their broad surfaces parallel with the lamination of the rock.

(3) Small aggregates of yellowish green scales of less transparency and lower polarization tints than the mica. These resemble rudimentary spots.

(4) Flecks of a dark grey cloudy substance. This probably represents

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(1) The Geology of North Wales. Geol. Survey Memoirs, Vol. III., Second Edition 1881), p. 125.

(2) *Loc. cit.*, p. 135.

(3) The metamorphic band has been mapped as a grit in the Survey Map of the district.

(4) Über den Spilosit und Desmoisit Zincken's. K. A. LOSSEN, Z. D. G. G., Band XXIV., 1872, p. 701. See also KAYSER, Über die Contactmetamorphose der körnigen Diabase im Hartz, Z. D. G. G., Band XXII. (1870), p. 103; and VON LASAULX, P. A., Band CXLVII., Stück 1, Heft 9, p. 141, Heft 10, p. 283.

earthy material of the original sedimentary rock, mixed perhaps with some chlorite.

(5) Black, opaque grains without metallic lustre. These are probably organic matter.

(6) Pyrites was observed in one case.

(7) The spots are formed mainly of chlorite. Sometimes they show a colourless border, sometimes a colourless nucleus. Single spots are more or less circular. By the coalescence of several spots oval or irregular forms are produced.

The existence of an isotropic substance in spilosite is, perhaps, somewhat doubtful. Prof. ROSENBUSCH says that he has not been able to detect it in specimens which he has examined.

The spilosite from the neighbourhood of Tremadoc does not answer precisely to the above description of the Hartz rock. Thus, the chlorite of the main mass often occurs in well defined scales with definite optic characters. The spots can scarcely be recognized under the microscope without the use of polarized light. Under crossed nicols they are at once defined by their poverty in the vividly polarizing mica. They appear dark. This darkness may be due to the presence of an isotropic substance, but it is more probably due to the presence of extremely minute overlapping chlorite scales. At best, the double refraction of the chlorite is extremely slight, and if scales overlapped compensation might be produced.

On the slopes of Y-Gesell, also near Tremadoc, another very different type of altered rock may be observed. It is compact, bluish grey in the centre but passing to white at the exposed surface. Tested with a knife it is found to scratch with difficulty, whereas the former rock scratches easily. There are no spots visible. This appears to be the kind of rock which in other localities is quarried for honestones. It answers to the *adinole* of the Hartz geologists. Under the microscope the rock is seen to consist of a micro- or crypto-crystalline aggregate of colourless minerals having the refraction and double-refraction of felspar, minute scales of mica and chlorite, and a few ragged specks of a substance which appears opaque by transmitted and white by reflected light (probably leucoxene after ilmenite). The mica and chlorite scales lie in the colourless aggregate. They are far less abundant in this rock than in the spilosite. One or two of the larger grains of the colourless aggregate show twinning, but as a rule the grains are simple, and so small that it is impossible to say whether they are quartz or felspar.

LOSSEN describes[1] the adinole of the Hartz as a compact, splintery rock, possessing approximately the hardness of quartz. It is generally light grey in colour, more rarely greenish grey. It consists essentially of a fine grained microscopic mosaic of quartz and soda-felspar (albite), the former mineral predominating over the latter. Calcite and pyrite also occur in some cases. ROSENBUSCH[2] calls attention to the existence of rutile

(1) Erläuterungen zur geologischen Specialkarte von Preussen. Blatt Harzgerode. Berlin, 1882, p. 35.

(2) Mik. Phy. d. Mass. Gest. 2nd Edit., 1886, p. 238.

both in adinole and spilosite. It occurs in short stumpy columns possessing very high refraction and double-refraction, and showing the characteristic heart-shaped and knee-shaped twin-forms. It never occurs in the slender acicular form characteristic of the clay-slates, although it may be found in this form (Shenck) in the immediate neighbourhood of the altered rocks. A thin dull white crust containing kaolin is formed by weathering.

The rock described as adinole from the neighbourhood of Tremadoc differs from the typical adinole of LOSSEN in containing scales of chlorite and mica. It resembles it, however, in general aspect and in mode of weathering. The latter point is one of importance, as it accords with the view that the colourless mosaic is formed in part of felspar.

The old flagstone quarry of Penmorfa, also near Tremadoc, furnishes other examples of contact metamorphism. A banded structure is very apparent and there is evidence of crumpling in some of the bands. Coarsely spotted rocks also occur. The banded varieties of contact rock were termed *desmoisite* by ZINCKEN. They resemble the spilosite in composition. In addition to the constituents already mentioned, the rocks from the flagstone quarry contain patches of calcite which extinguish simultaneously over large areas. Some of the larger colourless grains of the ground-mass can be positively identified as twinned plagioclase, and the extinction angles agree with those of albite. The following analyses by KAYSER show the composition of the contact rocks of the Hartz:—

	I.	II.	III.
SiO_2 ...	54·02	55·06	73·63
Al_2O_3 ...	21·22	19·75	15·81
Fe_2O_3 ...	2·51	1·83	—
FeO ...	6·48	7·55	0·74
MnO ...	1·74	—	—
MgO ...	3·01	2·21	1·21
CaO ...	1·64	3·59	1·02
Na_2O ...	3·36	7·51	8·33
K_2O ...	3·71	0·84	0·75
H_2O ...	1·97	1·83	0·61
Organic matter	tr.	tr.	—
	99·66	100·17	101·10
Sp. Gr. ...	2·778	2·813	2·678

I. Spilosite, Heinrichsburg. II. Desmoisite, Heinrichsburg. III. Adinolefels, Heinrichsburg. (1)

These analyses show that the distinction between spilosite and desmoisite, on the one hand, and adinole on the other must be due to an original difference in the character of the sediment. A striking feature is the large percentage of soda which the rocks contain. This has been proved by SHENCK (2) to be due to an actual impregnation of the sediment

(1) The analyses are taken from LOSSEN's paper, already quoted.

(2) Die Diabase des oberen Ruhrthals. Inaug. Diss. Bonn, 1884.

with alkali derived from the eruptive rock. Thus, at Bochtenbeck, by Niedersfeld, the unaltered rock contains 1·16 p.c. of soda, the altered rocks, 4·94, 4·56 and 3·59 p.c.; at Kuhlenberg, by Silbach, the unaltered rock contains 1·15, the altered rock, 7·14 p.c.; at Silberberg, the unaltered rock contains 0·50, the altered rock, 6·03 p.c. We are thus led to the important conclusion that *the albite of the rocks altered by diabase is largely if not wholly a secondary product due to the actual impregnation of the surrounding sediment by material derived from the eruptive rock.* Similar instances of impregnation may occasionally be found in the rocks surrounding granite-masses.

So far reference has been principally made to the granular diabases. In some localities we find rocks of similar mineralogical composition containing conspicuous porphyritic crystals of plagioclase. These are far less common than the granular diabases. Mr. TAWNEY described a good example of this type,[1] from the hill designated as a Trigonometrical station one and a-half mile N.N.E. of Pwllheli. He terms the rock a diabase-porphyrite. It is characterized by porphyritic felspars, up to a quarter inch in length, embedded in a dark green ground-mass. Under the microscope the felspars are seen to be much decomposed. They are represented partly by diverging zeolite-needles and partly by indistinct granular matter. The ground-mass contains augite in crystals and granular aggregates, ilmenite and pseudo-amygdules containing chlorite and other substances.

The basic rocks of the Lleyn peninsula and Anglesea frequently contain hornblende and olivine. By the increase in one or other of these constituents the diabases pass into hornblende-diabases, diorites, and hornblende-picrites.

Compact augitic greenstones with interstitial matter (melaphyres or altered basalts) are comparatively rare in North Wales. At least they have not as yet received much attention if they occur on any extensive scale. Such rocks occur near the top of Cader Idris. Under the microscope one recognizes minute, lath-shaped sections of felspar, granules of augite and dirty brown interstitial matter. Rocks of this type are sometimes vesicular and thus possess all the petrographical characters of lava flows.

A consideration of the facts given above only serves to show how extremely meagre our information as to the basic plagioclase-augite rocks of North Wales really is. The most important points which have been established with regard to them are:—

(1) The existence of a granular ophitic diabase in the form of intrusive sheets at many points in Merionethshire and Caernarvonshire.
(2) The occurrence of well-marked contact-metamorphism at the junctions of these sheets with the sedimentary rocks.
(3) The occurrence of brown hornblende, olivine and mica in some of the diabases of the Lleyn Peninsula and Anglesea.
(4) The occurrence of diabase porphyrite and melaphyre (altered plagioclase-augite rock with interstitial matter) in certain localities.

(1) G. M. Decade II., Vol. VII., 1880. p. 452.

(5) The local passage of diabase into a chloritic schist in consequence of a deformation of the rock mass.

(6) The existence of numerous more or less vertical dykes some of which must be referred to a later period than the intrusive sheets.

With regard to the age of the sheets, it seems probable that they belong on the whole to the same period as the associated lavas of more acid composition. If this be so, the sheets of Merionethshire would belong to the Arenig, and those of the Snowdonian area to the Middle Bala period.

Mid-Wales.—Stanner Rock and Hanter Hill, near old Radnor, are largely composed of basic igneous rocks for a description of which we are indebted to Mr. COLE.[1] These rocks vary both in texture and composition. The principal constituents are plagioclase, in one case determined to be labradorite; augite including diallage; a rich brown biotite; opaque iron ores; a green fibrous alteration product, probably after enstatite; acicular and compact hornblende, after augite; chlorite after hornblende, augite and biotite; and quartz. Olivine is stated by Mr. COLE to have been very probably a constituent of the summit masses of Hanter Hill.

A fine-grained holocrystalline rock from Stanner, having a specific gravity of 2·86, consists essentially of plagioclase, augite, rich brown mica, titanoferrite and apatite. The mica and augite are often closely intergrown, and both pass over into green alteration products among which hornblende is occasionally recognizable. This rock bears a close relation to the mica-dolerites from the neighbourhood of Saltash, Plymouth, hereafter to be described. As a rule the rocks of Stanner are granular in texture. They are traversed by veins of pegmatite and granophyre, the latter rock frequently showing the closest resemblance to the rock which forms the summit of Carrock Fell.

Mr. WATTS has described a group of intrusive igneous rocks from the Breidden Hills, on the borders of Shropshire and Montgomeryshire, which may be referred to in this connection. They are essentially composed of plagioclase, augite, a rhombic pyroxene and magnetite or ilmenite, together with various alteration products. Two generations of felspar are frequently recognizable, and the structure is often ophitic. The rocks are enstatite-diabases.

South Wales.—Basic igneous rocks are largely developed in the neighbourhood of St. David's, Pembrokeshire. They consist of lavas, tuffs, intrusive sheets and dykes. The contemporaneous rocks belong to the Pebidean (pre-Cambrian) of Dr. HICKS, but are referred to the base of the Cambrian by Dr. GEIKIE. The intrusive rocks are in part of later date. The petrographical characters of these ancient basic rocks have been described by Dr. HICKS,[2] Mr. DAVIS,[3] Mr. TAWNEY,[4] and Dr. GEIKIE.[5]

The basic lavas are described by Dr. GEIKIE as "dull, fine-grained

(1) The Igneous Rocks of Stanner. G. M., Decade III., Vol. III., p. 219, 1886.
(2) Q. J. G. S., Vol. XXXIV., p. 147; see also Proc. Geol. Ass., Vol. VII., p. 63.
(3) Q. J. G. S., Vol. XXXIV., p. 166.
(4) Proc. Bristol Naturalists' Soc., Vol. II., Part 2, p. 109.
(5) Q. J. G. S., Vol. XXXIX., p. 293.

to compact, sparingly porphyritic, ranging in colour from an epidote-green to dull blackish-green and dark chocolate-brown. Some of them are finely porphyritic from the presence of small glistening surfaces which present the colour and lustre of hematite and yield its characteristic streak." The alteration to which the rocks have been subjected makes it difficult to determine their original characters with precision. They must, however, have contained a variable amount of base together with augite-granules, magnetite, felspar not now generally recognizable, and olivine. Pseudomorphs of the latter mineral now occasionally give a porphyritic character to the rocks. Dr. GEIKIE terms the rocks olivine-diabases. The presence of base would remove the rocks from the diabases of Professor ROSENBUSCH and place them under the melaphyres. There can be no doubt that they were originally olivine-basalts.

The basic tuffs associated with the above rocks are usually purple, red or dark green. They vary in texture from coarse breccias or agglomerates to "fine silky schists in which the tuffaceous character is almost lost." The following analyses, quoted from Dr. GEIKIE'S paper, show the similarity in composition of the tuffs and lavas :—

	I.	II.	III.	IV.
SiO_2 ...	51·25	48·11	45·92	45·38
Al_2O_3 ...	20·41	13·30	18.16	16·62
Fe_2O_3 ...	3·02	3·70	1·18	4·06
FeO ...	3·91	8·10	9.27	8.63
MnO ...	0·21	1.43	0.19	0·14
CaO ...	4·53	8·48	7·19	8·19
MgO ...	7·22	9·51	10·07	9·41
K_2O ...	2·93	1·57	1·78	0·71
Na_2O ...	1·82	1.96	2·12	2·20
Loss on Ig.	5·02	4·21	4·22	4·34
Insol. ...	—	—	0·04	0·08
	100·32	100·37	100·14	99·76
Sp. Gr.	2·84	2·92	2·96	2.99

I. Purplish-red shaly tuff from below the olivine-diabase crag, Rhosson (WILSON).

II. Dull purple and green tuff from the lowest group of tuffs between Pen-maen-melyn and Pen-y-foel (WILSON).

III. Olivine-diabase, Rhosson (WILSON).

IV. Olivine-diabase, Clegyr Foig (WILSON).

The dykes and intrusive sheets of basic rock occur in all the other rocks of the St. David's area. The dykes are especially abundant in the Dimetian of Dr. HICKS. The rock of the dykes and sheets is much decomposed. It differs from that of the older lavas "in the abundance and freshness of its felspars, in the comparative scarcity of its augite and in the absence of olivine" (GEIKIE). This description implies that it is, or rather was, an andesitic dolerite.

Outside the St. David's area we find many other exposures of basic igneous rock in Pembrokeshire. These are included under the general colour for "greenstone" on the geological map, but it must be remembered that this colour has also been extended over areas occupied by rocks of intermediate and even acid composition.

A considerable exposure of diabase essentially similar to that associated with the Lower Palæozoic rocks of North Wales occurs in the neighbourhood of Fishguard. It is well exposed near the village of Llanwnda. The dominant rock is a medium grained ophitic diabase (no olivine), with much chlorite and epidote. The chlorite occurs in fine-grained, irregular and spherulitic aggregates, and often contains detached grains or granular aggregates of epidote. Irregular patches of a coarse-grained rock containing long, narrow-bladed crystals of augite occur in the normal ophitic diabase. The augite-individuals in the coarse-grained rock show a decided approach to crystalline form, and they are almost invariably twinned in accordance with the ordinary law. The felspars are as a rule more or less cloudy in consequence of alteration. When examined with a high power the cloudiness is frequently seen to be due to the development of ill-defined flecks and granules of a vividly polarizing mineral. Ragged plates and skeleton crystals of ilmenite are abundant, and are as a rule more or less changed to leucoxene. The diabase above referred to produces marked contact alteration on the surrounding sediments. A magnificent series of basic lava flows occurs in Skomer Island. The successive flows are sometimes very thin and highly vesicular. Green earth and calcite occur in the cavities, and veins of epidote and quartz are not unfrequently seen traversing the rocks. Most of the rocks are considerably altered, but some are very fresh. They consist essentially of small lath-shaped felspars, granules of augite and magnetite. Well-characterized serpentinous pseudomorphs after olivine occur sparingly in certain varieties. Interstitial matter occurs only in very small quantity. Some varieties are rendered porphyritic by the occurrence of felspar and aggregates of chlorite which may possibly represent augite. The ground-mass of the porphyritic rocks, and the general mass of the non-porphyritic rocks is compact in texture and often shows under the microscope a well-marked fluxion structure. The rocks contain too much felspar and too little olivine to be perfectly typical olivine-basalts; nevertheless they are evidently basic rocks. The specific gravity of a typical specimen is 2·87.

Lake District.—Basic igneous rocks have not as yet been described as occurring in any great abundance in the Lake District. In his Memoir on Sheet 101, S.E., Mr. WARD proves that the dominant type of igneous rock in this district is of intermediate composition. He mentions intrusive dolerites (diabases) from only four localities: Wythop Fells, Castle Head near Keswick, Swirral Edge near the summit of Helvellyn, and Longstrath in Borrowdale. None of these are very typical, and all are highly altered. The rock of Castle Head may be conveniently designated a mica-diabase. The ground-mass is composed of turbid plagioclase, irregular plates of a brown, strongly-pleochroic biotite, skeletons of titaniferous iron-ore more

or less changed to leucoxene along narrow parallel bands, and a little quartz and chlorite. In this groundmass lie aggregates of irregular augite-individuals, often frequently twinned, and serpentinous pseudomorphs after olivine or enstatite, probably the latter.

The rock from Swirral Edge is mentioned by Professor ROSENBUSCH as a typical leucophyre.(1) GUMBEL'S definition of this term has been already quoted (p. 135). ROSENBUSCH considers that the distinguishing characteristics of the group must be looked for in the large excess of plagioclase over augite and the entire absence of magnesia-mica and hornblende. Quartz is generally present and is in part, if not entirely, an alteration product. Calcite and chlorite are very common. A specimen from Swirral Edge collected by the author shows under the microscope a large amount of turbid felspar, indistinct pseudomorphs of calcite dust and chlorite after augite, probably ophitic, and brownish leucoxene plates after ilmenite. In the hand specimen the rock is pale in colour for a diabase and therefore in this respect answers to GUMBEL'S definition of leucophyre.

The typical ophitic diabases, so common in North Wales, have not as yet been recognized as occurring in the Lake District in any quantity. A rock of this character is found, however, at Walla Crag, Haweswater. Under the microscope the most conspicuous mineral is a nearly colourless pyroxene which occurs in large opbitic plates. Next in importance are greenish pseudomorphs of fibrous structure. These occur independently in the rock and also as inclusions in the augite. Under crossed nicols they split up into isotropic or nearly isotropic and vividly polarizing portions. The latter form a very irregular network, and the isotropic portions form the centres of the meshes. The vividly polarizing portions extinguish simultaneously. These are in all probability pseudomorphs after a mineral belonging to the enstatite-group. The lath-shaped felspars are highly altered and give now only aggregate polarization. Titaniferous iron ores and apatite are present. The rock appears, therefore, to be an ophitic enstatite diabase.

The lavas of the Lake District appear to be as a rule of intermediate composition (altered andesites). Mr. WARD(2) has, however, called attention to the existence at Eycott Hill of a fine series of lava flows and ash-beds of a somewhat basic character (51 to 53 per cent. of silica). Professor BONNEY (3) has recognized the existence of a rhombic pyroxene in these rocks. Mr. WARD indicates fourteen distinct flows in his section. The second of these, reckoning from the base of the section, is the most remarkable. It is vesicular in its upper portion and the vesicles are drawn out along the line of flow. They are now filled with chlorite chalcedony and quartz. The main mass of this rock is rendered

(1) Massige Gesteine. Second Edition. 1886. p. 200

(2) Q. J. G. S., Vol. XXXI., p. 406 ; Microscopical Journal, 1877, p. 239. See also Survey Memoir on Sheet 101 S. E.

(3) G. M., 1885, p. 76.

conspicuously porphyritic by the occurrence of large felspar crystals. These crystals appear often clear and glassy on a fractured surface and the sections thus exposed are generally longer than broad. The tabular form is not very pronounced; nevertheless, there is a tendency to this form, the brachy-pinacoid being the best developed face. The prismatic angles are often rounded. Sections of this felspar measuring an inch in length are not uncommon. Very often the crystals are binary Carlsbad twins, and at a time when this type of twinning was regarded as characteristic of orthoclase this feature led to the belief that orthoclase was present in the rock. The crystals referred to invariably show the twin-striation of plagioclase on the basal cleavage in addition to the appearance indicative of Carlsbad twinning. The writer is not aware of the existence in Britain of any other plagioclase in which the co-existence of twinning on the Carlsbad and albite types can be easily recognized by the naked eye. Cleavage flakes of this felspar do not give absolutely constant extinction, but they always indicate a felspar belonging to the labradorite-bytownite series. One parallel to (010) gave an extinction of 28° in a minus direction, and showed in convergent light an optic axis just outside the field of view. Another parallel to (100) gave an extinction of 13° referred to the trace of the cleavage parallel to (010). These two observations agree very well and point to a felspar of the composition $Ab_1\ An_2$. The specific gravity lies between 2·7 and 2·71, and appears to be generally nearer the former than the latter. The fusibility is about 1 of Szabo's scale, a fact which points to bytownite rather than labradorite; the soda-flame, on the other hand, is stronger than in typical bytownite. We may conclude from these facts that the felspar is a somewhat basic ladradorite.

This felspar often shows under the microscope a zonal structure due to the arrangement of minute inclusions. One section of a large felspar (1in. by ½in.) taken approximately parallel to the basal plane illustrates this phenomenon in a very perfect manner. Two kinds of inclusions may be recognized (1) extremely minute and more or less spherical cavities, (2) larger inclusions, filled with opaque material and having more or less the form of the section in which they lie (negative crystals). The former are aggregated in narrow bands and define the zonal structure; the latter are not very numerous and are distributed without much regularity. The central portion of the crystal is tolerably free from original inclusions. A few negative crystals may be recognized, but the zonal structure due to the minute inclusions is absent. In the external portion of the crystal the zones are extremely numerous. They are crowded together in the direction of the short diameter of the section, but they open out in the direction of the long diameter. Not only are the spaces between the different bands of inclusions wider in the latter direction, but the breadth of each individual band of inclusions is also wider. This indicates that the crystal grew more rapidly in the direction of the brachy- than in that of the macro-diagonal axis. The more or less tabular form of the large porphyritic crystals is

evidently developed during the growth of the crystal, and is a consequence of the fact that less material is added in the direction of the macro-diagonal than in directions at right angles to this. Indications of the prism faces (110 and $1\bar{1}0$) may be observed in the zones of inclusions, but the angles are more or less rounded as is the case with the angles of the crystal itself.

In addition to the large felspar-crystals there are small green spots which represent pseudomorphs after a pyroxene. Under the microscope crystals of augite, often twinned, may also be occasionally seen (WARD). The greenish spots have been identified by Prof. BONNEY as pseudomorphs after a rhombic pyroxene. They are generally a pale sap green by transmitted light. Longitudinal sections show a faint pleochroism ; pale green for rays vibrating parallel to the length of the section and yellowish green for rays vibrating at right angles to this direction. They polarize in weak tints, often showing the dark bluish tint of the first order, and always give straight extinction. This mineral may be regarded as a variety of bastite. It is interesting to observe that whereas the enstatite is almost always altered, the augite is fresh. The enstatite, as Prof. BONNEY points out must have largely exceeded the augite in amount. Many slides show no augite in the form of porphyritic crystals.

The above porphyritic constituents lie embedded in a greenish-blue or dark slate-coloured matrix. Under the microscope this is resolved into lath-shaped plagioclase, augite granules, magnetite and brown interstitial matter. The interstitial matter is crowded with indistinct brownish granules and small grains of magnetite. Sometimes it contains also curved felspar microlites. It bears a close resemblance to the interstitial matter of the andesitic-dolerites (augite-andesites) which occur as dykes in the north of England (*e.g.* Cockfield dyke). Prof. ROSENBUSCH [1] refers to a rock from Penrith which he states is essentially analogous to the Labrador-porphyries of the Vosges. He classes it as a diabase-porphyrite. The specimen referred to probably came from Eycott Hill. A more definite idea of the character of the rock may be given by designating it a labradorite-pyroxene-porphyrite.

The lava flows which succeed the above are not characterized by such conspicuous felspar-crystals. Some appear compact and non-porphyritic. As a general rule, however, two generations of felspar may be detected under the microscope. The ground-mass in all those which have been examined consists of lath-shaped plagioclase, augite in minute granules, magnetite and interstitial matter. The state of crystallization of the ground-mass varies considerably. In some the constituents may be recognized with a low power, in others they are so small as to require a high power for their examination. The following analyses were made for Mr. WARD by Mr. JOHN HUGHES [2].

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(1) Massige Gesteine, 1st edition, p. 385.

(2) Microscopic Journal, 1887, p. 246.

	I.	II.	III.
SiO_2 ...	53·300	52·600	51·100
Al_2O_3 ...	20·990	17·315	22·051
Fe_2O_3 ...	1·660	1·722	1·210
FeO ...	6·343	12·043	5.885
CaO ...	8·512	7·728	11·424
MgO ...	3·964	3·252	2·346
Na_2O ...	2·456	2·622	2.216
K_2O ...	·926	1.486	1·022
P_2O ...	·102	·153	·179
CO_2 ..	·320	·140	1·820
Loss ...	1·120	1.160	·710
	99·693	100·221	99·963 (1)

I. Micro-porphyritic lava forming bed 12 in WARD'S section.
II. Compact lava forming bed 13.
III. Porphyritic lava forming bed 15.

Many of the valleys which drain the northern side of the hilly district running from Skiddaw to Carrock Fell contain boulders of porphyritic rocks resembling to some extent the labradorite-pyroxene-porphyrite of Eycott Hill. The rocks are in general lighter in colour than those of Eycott Hill. A specimen from Roughten Gill contains small patches, about equal in size to some of the porphyritic felspars, but without their characteristic form, consisting of aggregates of zoisite, calcite and chlorite. The zoisite occurs in long colourless prisms with a well marked cleavage parallel to the prisms and cross jointing at irregular intervals. It is colourless and possesses moderately strong refractive power. The prisms give straight extinction and polarize in the weak bluish tints of the first order.

An interesting question arises as to the connection between the plutonic rocks of Carrock Fell and the volcanic rocks of Eycott Hill and the northern part of the Skiddaw region. Mr. WARD regarded the former as the metamorphosed representatives of the latter. May they not rather in part represent the same magma cooled under plutonic conditions? Some of the quartz-gabbros or augite-diorites certainly resemble the Eycott Hill lavas in composition.

West of England.—The basic igneous rocks of the West of England belonging to the group now under consideration—the so-called greenstones—are of exceptional interest on account of the extent to which they have been metamorphosed by the post-carboniferous earth-movements, and by the intrusion of large masses of granite. Devon and Cornwall, together with Brittany constitute a part of an old chain of highlands which formed a marked feature in the physical geography of northern Europe during Mesozoic times. The Devono-Carboniferous and pre-Devonian rocks of which this chain was composed are concealed at intervals by Mesozoic and Tertiary strata, but wherever they come to the surface, as is the case in the Ardennes, the Eifel, Westphalia, Nassau,

(1) These analyses are given in Mr. WARD'S paper as adding up to 100 in each case.

Thuringia, and the Hartz, they present the same palæontological, stratigraphical and petrographical characteristics. The chain acquired individuality towards the close of the Palæozoic epoch in consequence of the extensive crumpling of the Palæozoic sediments and their associated igneous rocks. The final relief of the intense stresses which produced this crumpling appears to have been afforded by the intrusion of granite at many points along the chain.

The igneous rocks associated with the Devonian and pre-Devonian sediments are partly intrusive and partly contemporaneous (lavas and tuffs). They present essentially the same characters wherever they occur. The rocks of the Hartz and the Fichtelgebirge are often undistinguishable either in respect of their original or secondary characters from those of Devon and Cornwall. It is an unfortunate circumstance that the exact boundary which separates the Lower Palæozoic from the Devonian strata has not yet been traced in the west of England, and we are therefore in doubt as to the precise horizons at which some of the igneous rocks occur. The difficulty experienced in tracing this boundary is undoubtedly to be attributed in great measure to the powerful character of the post-Carboniferous earth-movements. These have so masked the original junctions, modified the strike of the earlier rocks and metamorphosed the sediments that what appears now as a geological unit may after all be a complex of different formations. For our present purpose it will be convenient to separate the basic rocks of the Lizard District from those of the rest of Cornwall and Devon. The latter are associated with Devono-Carboniferous and Lower Palæozoic strata, and they have been metamorphosed in early Carboniferous or post-Carboniferous times; the former are associated with gabbro and serpentine and the period of their metamorphism has not yet been absolutely determined.

The basic igneous rocks, associated with the Palæozoic sediments, occur as lavas and tuffs, and also as sheets and dykes. The unquestionable lavas and tuffs are found in Devon and East Cornwall. They are associated with Devonian strata. In West Cornwall there are certain green hornblendic rocks which may be in part metamorphosed tuffs. Dykes and veins of greenstone are rare, except in the Lizard District.[1]

We are principally indebted to Messrs. ALLPORT,[2] PHILLIPS,[3] RUTLEY,[4] and WORTH [5] for the information we possess as to the petrographical characters of the "greenstones" of the West of England. The description of these rocks is attended with considerable difficulty in consequence of variations in structure and composition in one and the same

(1) The dykes of mica-trap will be described in a subsequent chapter. Some of these, as for example those of Towan Head, near New Quay, closely resemble greenstone. They are, however, of later date than the rocks now under consideration.

(2) Q. J. G. S., Vol. XXXII., 1876, p. 407.

(3) Q. J. G. S., Vol. XXXII., 1876, p. 155, and Vol. XXXIV.; 1878, p 471.

(4) The Eruptive Rocks of Brent Tor and its Neighbourhood. Mem. Geo. Survey, 1878; Q. J. G. S., Vol. XXXVI., 1880, p. 285, and Q. J. G. S., Vol. XLII., 1886, p. 392.

(5) The Rocks of Plymouth. Trans. Plymouth Inst. &c., 1886.

rock-mass. These "greenstones" admirably illustrate the impossibility of separating rocks into sharply defined groups. We can describe the rocks, but to give each specimen a name which shall connote its characters is impossible.

The variations in structure are partly original and partly secondary. The most important secondary structural characteristics are those which depend on the development of foliation. Mr. PHILLIPS frequently refers to the gradual passage from a crystalline massive rock, in which the individual constituents are related to each other as in normal igneous products, to a foliated rock which "does not exhibit any of the characteristics peculiar to igneous rocks." He mentions a rock-mass occurring a little west of St. Austell as exhibiting this gradual change in a very satisfactory manner.

The variations in composition are also partly original and partly secondary. The most important secondary characters depend upon the development of chlorite or some form of hornblende at the expense of the original augite; of leucoxene and ultimately granular sphene or rutile at the expense of the titaniferous iron-ore; and of water-clear secondary felspar (? albite) and other substances at the expense of the original plagioclase. In describing the rocks we shall deal first of all with the lavas and tuffs, then with the more distinctly crystalline rocks and their metamorphic representatives, and lastly with the hornblendic slaty rocks of more or less doubtful origin.

Lavas and tuffs occur in the neighbourhood of Plymouth and Tavistock in Devon, and of St. Minver (Pentire Point), and other localities in East Cornwall. They are probably also represented in West Cornwall, but the metamorphism in this region has been so intense that it is impossible to speak with absolute certainty on this point. The most typical lavas are locally known as "dunstones." They are usually of a greenish-grey colour and finely amygdaloidal; the cavities being filled with calcite, chlorite, and quartz; zeolites are rare. They correspond to the "diabas-mandelstein" of Continental authors. Owing to their extensive alteration by surface and other agencies it is extremely difficult to determine their original characters.

Microscopic sections usually show minute lath-shaped felspars in a ground-mass, rendered more or less opaque by opacite and various decomposition products. Recognizable augite is comparatively rare. In a rock from Pentire Point, near St. Minver, it occurs in the granular form, characteristic of many basalts. Ill-defined green alteration products (viridite), are, however, frequently present and doubtless represent an original ferro-magnesian constituent. In some instances (*e. g.*, lavas of Landrake and Honicknowle) porphyritic crystals of plagioclase may be recognized as well as the minute lath-shaped felspars of the ground-mass. In a remarkable rock from Egg Buckland, described by Mr. WORTH, the porphyritic elements consist of globular holocrystalline aggregates of twinned felspar (glomero-porphyritic structure). Unaltered basic glass is not known as a constituent of these lavas, but the researches of Mr.

RUTLEY make it highly probable that such a substance existed. It is now represented by a greenish-yellow or brownish-yellow substance (palagonite), often crowded with vesicles. Many of the lavas show good fluxion structure in thin section. They also frequently possess schistosity which runs parallel with that of the adjacent sedimentary rocks.

The tuffs, so far as their composition can now be ascertained, consisted of broken plagioclase-crystals, vesicular lapilli and small fragments of rock similar to the compact lavas. Vesicular and minutely disintegrated basic glass probably entered largely into their composition. Tufaceous material may be recognized in many of the sedimentary rocks.

The following analyses by Mr. PHILLIPS will give an idea of the composition of the lavas and tuffs and at the same time illustrate the very large amount of alteration which has taken place in consequence of the percolation of water charged with carbonic acid :—

	I.	II.	III.
SiO_2	43·23	40·05	36·74
Al_2O_3	21·37	20·46	17·55
Fe_2O_3	1·69	1·83	1·62
FeO	9·53	12·66	8·23
MnO	tr.	tr.	tr.
CaO	6·66	6·62	12·08
MgO	3·57	4·28	6·04
Na_2O	5·63	4·82	3·08
K_2O	tr.	tr.	·74
CO_2	2·61	3·67	9·10
P_2O_5	·97	·63	·35
FeS_2	·33	tr.	—
H_2O	4·49	4·86	4·31
	100·08	99·88	99·84
Sp. Gr.	2·82	2·83	2·82

I. Amygdaloidal lava from Pentire Point.
II. Schistose amygdaloidal lava from Port Isaac.
III. Rock from Bokelly, in the Parish of St. Kew, resembling an indurated ash.

The more distinctly crystalline rocks, most of which were probably intrusive, have been much less affected by surface agencies than the undoubted lavas and tuffs. They have, however, been profoundly modified by contact and dynamic metamorphism. As a result we frequently find one and the same rock-mass exhibiting considerable variations of structure and composition, In dealing with these rocks it is of the utmost importance that we should distinguish, if possible, between those which contain original and those which contain secondary hornblende. In this work we regard the deep brown "basaltic" hornblende as original. Now this occurs in a few localities and especially in the neighbourhood of Saltash. It is found intergrown with augite and also in independent crystals which show the clino-pinacoid (010) as well as the prismatic faces (011), Every other kind of hornblende in the rocks now under consideration we regard as secondary. This secondary hornblende is usually fibrous (uralitic) or

actinolitic. Less frequently it occurs in the form of irregular crystalline grains which are not fibrous. It will then be spoken of as compact hornblende. It varies somewhat in tint, but is almost always some shade of green. One variety, commonly occurring in the form of actinolite, shows the following pleochroism:—*a*, very pale green; *β*, green; *γ*, rich bluish green or greenish blue. This is especially found near the granite masses. A pale brown, fibrous hornblende (brown uralite) is sometimes present. For purposes of distinction we shall speak of the rocks containing original hornblende as hornblende-dolerites or -diabases, and limit the terms proterobase and epidiorite to those with secondary hornblende. Thus the original rocks may be roughly divided into two groups.

(1) Dolerite or diabase proper.

(2) Hornblende-dolerite or -diabase.

A deep brown biotite is often associated with the basaltic hornblende and sometimes occurs to the exclusion of the latter. The varieties thus produced may be designated hornblende-biotite-dolerite and biotite-dolerite.

Turning now to the rocks with secondary hornblende, and leaving out of account those which show more or less foliation, we note every gradation from a rock essentially composed of plagioclase, augite and iron-ore, to one formed essentially of plagioclase, hornblende and iron-ore. To the latter variety we shall apply GÜMBEL'S term, epidiorite. The term proterobase will be applied to rocks in which more or less original augite remains. According to this nomenclature uralite-diabase becomes a variety of proterobase. It must not be supposed that there is any sharp line between dolerite (diabase), proterobase and epidiorite. One and the same rock-mass may furnish all three varieties. The terms proterobase and epidiorite are merely used for the purpose of shortening descriptions.

The dolerites almost invariably contain a certain amount of chlorite and other alteration products. They may therefore be spoken of as diabases. They frequently exhibit the ophitic structure in the greatest perfection and relics of this structure are often preserved in the proterobases and epidiorites. When this is the case the adjective "ophitic" will be used in speaking of these rocks. This preservation of the ophitic structure in many of the epidiorites is of the utmost importance because ophitic epidiorites frequently pass by the most insensible gradations into foliated rocks the origin of which would otherwise remain a mystery.

Having explained the nomenclature which we shall adopt we proceed to consider the rocks in greater detail. The least altered rocks occur in the eastern portion of the district; that is in Devon and east Cornwall.

Typical ophitic diabases have been observed at Yealmpton, Rock, Park House near Dartington, Pollaphant, Catacleuse near Padstow, South of Anstie's Cove near Torquay and at South Pretherwin. The felspars are always more or less turbid in consequence of alteration. They occur in forms giving lath-shaped sections. The augite is pale in colour and occurs in large ophitic masses. It is often seen to have been more or less replaced by green chloritic minerals in which

dusty magnetite and grains or well-formed crystals of epidote frequently occur. The titaniferous iron-ore occurs in ragged masses often made up of parallel rows of plates intersecting at angles of 60° and 120°. It is often transformed into leucoxene and sometimes into granular aggregates of vividly polarizing sphene. Calcite and quartz often occur as secondary products. Apatite is almost always recognizable.

The rocks just described bear the closest resemblance to the ophitic diabases of North and South Wales. Olivine, at any rate as a rule, is conspicuous by its absence. Diabases with porphyritic crystals of felspar appear to be rare. They occur, however, in some localities, as for example at Addicombe near Torquay.

The diabases of the above type occasionally become schistose. A good example of this occurs at Hope's Nose near Torquay. The rock is of a dark greenish colour and possesses a marked schistosity. Under the microscope it is seen to consist of pseudomorphs after ophitic augite, a water-clear felspar (? albite) which is associated with much calcite in the form of fine powder, and titaniferous iron partially replaced by leucoxene. In some places the leucoxene consists of granules of vividly polarizing sphene. In portions of the slide the ophitic structure is replaced by a micro-flaser structure which marks the planes of schistosity; that is the planes along which movement has taken place. This rock has been profoundly affected by surface agencies as well as by dynamic metamorphism. At the Town's Mills quarry near Liskeard there occurs a green slaty rock of an exceptionally interesting character. It shows a marked fissility and splits readily into thin slabs. A thin section cut at right angles to the schistosity shows a well defined micro-flaser structure. The constituents are plagioclase, chlorite and iron-ores mainly pyrites. The felspar is very fresh but gives everywhere evidence of having suffered from great mechanical disturbance. The twin lamellæ are bent and the individuals are often broken. The chlorite is arranged in many planes which wind in and out amongst the broken felspathic matter and thus define the flaser structure to which the schistosity of the rock is due. The rock was in all probability a massive dolerite. It is now a felspathic chlorite-schist.

The dolerites (diabases) containing basaltic hornblende and rich brown mica (not the pale brown mica so frequently developed near the contact with granite) appear to be much less common than the normal ophitic diabases. They have been recognized at Wearde, Ernsettle, Grove and Treluggan in the Plymouth district; also near St. Minver in North Cornwall. A rock from Treluggan consists of a matrix of cloudy felspar, containing somewhat ill-formed crystals of basaltic hornblende, colourless augite, plates of deep brown biotite, grains of titaniferous iron-ore and large hexagonal prisms of apatite with central cores. A fair amount of chlorite has been formed in consequence of the alteration of the ferro-magnesian constituents. A rock from Wearde belonging to the same group resembles a syenite in external appearance in consequence of the pink colour of the felspar. In microscopic structure and com-

position it resembles the former. A rock from Ernsettle may be described as an ophitic mica-bearing diabase containing much apatite. The abundance of the apatite in these rocks is often a striking feature. Deeply coloured augites are comparatively rare in the basic rocks of the West of England. They occur, however, in the "Bottor Rock" near Bovey Tracy. This rock contains biotite together with much iron-ore and apatite. The hornblende- and biotite-bearing diabases of the West of England have affinities with the hornblende-diabases of North Wales described by Mr. TAWNEY (see Fig. 1, Plate VIII.). It is interesting to note that both in North Wales and the West of England we have normal ophitic diabases and hornblende-diabases and that in both districts the former rocks are much more extensively developed than the latter.

We have now to consider the metamorphic phenomena described by ALLPORT and PHILLIPS. These are identical with the phenomena described by LOSSEN,[1] LIEBE,[2] SHENCK,[3] and RENARD[4] as occurring in the Hartz, Thuringia, Westphalia and the Ardennes; that is in the other portions of the old mountain axis of northern Europe.

It has already been mentioned that the metamorphism is more marked in the west than in the east. In Devon and eastern Cornwall we frequently find rocks which retain many of the characters they possessed at the time of consolidation. In western Cornwall, on the other hand, it is rare to find rocks in which these characters have not been to a great extent destroyed. In many cases the chemical composition is almost the only original character which the rocks have retained; and, in some cases there is reason to believe that even this has been considerably modified. In mineralogical composition and texture many of these rocks are far removed from normal igneous products and closely allied to the crystalline schists. In the neighbourhood of the granite-masses, especially those of Dartmoor and the Land's End, we find highly metamorphosed dolerites. These have been described by Messrs. ALLPORT, PHILLIPS, and RUTLEY. Precisely similar rocks have been described by LOSSEN from the contact zone of the Rammberg mass of granite. The examination of a large series of sections is absolutely essential to the correct appreciation of the character of the metamorphism. Various stages of metamorphism may frequently be observed in one and the same rock-mass. The most striking feature is the replacement of augite by hornblende. Every gradation may be observed from a rock extremely rich in augite to one in which no trace of augite remains. The disappearance of the augite is invariably accompanied by an increase in the amount of hornblende or chlorite, generally the former. The hornblende

(1) Jahr. d. k. preuss. geol. Landesanstalt für 1883, und 1884.

(2) Übersicht über den Schichtenaufbau Ostthüringens. Abh. z. geol. Specialkarte von Preussen, &c. Berlin, 1884.

(3) Die Diabase des oberen Ruhrthals, Inaug. Diss. Bonn, 1884.

(4) La Diabase de Challes. Bull. Acad. Roy. Belg. Vol. XLVI., 1878.

is as a rule green in colour and either uralitic or actinolitic. Specks and granules of opaque iron-ore are frequently associated with the uralitic aggregates which are less markedly pleochroic than the actinolitic hornblende. Occasionally a pale brown uralite may be observed. The original felspar, when present, gives more or less turbid lath-shaped sections; very frequently, however, the felspar is represented by water-clear aggregates composed of large irregular individuals, or else showing mosaic structure (see Fig. 2, Plate XXI.). That these aggregates are secondary is proved by the fact that they are often crowded with needles of secondary hornblende. The only other essential mineral in these rocks is titaniferous iron-ore, often more or less changed to leucoxene. A pale brown mica, distinct from that of the hornblende-biotite-dolerites, is very common as an accessory constituent. Tourmaline, garnet and axinite are less common. Apatite is usually present and secondary quartz is by no means rare.

A rock from the White Tor near Tavistock furnishes a good example of a tolerably advanced stage of metamorphism. It consists of hornblende, felspar, titaniferous iron-ore, pale brown mica (contact mica), and a little tourmaline. The hornblende is mostly uralitic or actinolitic. The uralite is pale in colour, sometimes showing a decided brown tint. The typical actinolite is strongly pleochroic; a, pale green; β, green; γ, bluish-green. Dots and specks of magnetite are common in the feebly pleochroic but absent from the strongly pleochroic varieties of hornblende; a fact which, as LOSSEN remarks, points to the conclusion that the pleochroism increases with the amount of iron (Fe_2O_3), in the hornblende molecule. *The uralitic aggregates are penetrated by pseudomorphs after lath-shaped felspars;* a point of great importance, as it proves that the original rock was an ophitic dolerite. The spaces between the patches of uralitic hornblende are now principally occupied by a colourless matrix, sometimes granular and sometimes water-clear, in which detached needles and groups of actinolite crystals are extremely abundant. This matrix is an aggregate of irregular grains, mostly untwinned, of secondary felspar. The general relation of the hornblende and felspar in those portions of the slide which do not show a marked ophitic texture is similar to that represented in Fig. 1, Plate XX. The titaniferous iron-ore occurs in extremely ragged plates and is exactly similar to that of the normal ophitic diabases. *It preserves its form and character better than any other mineral.* In studying metamorphosed dolerites (diabases) the present writer has found the titaniferous iron-ore and its characteristic alteration products, leucoxene and granular sphene, of the greatest use. They will frequently give a clue to the origin of even a foliated rock when almost every other trace of the original character has disappeared.

The above rock from the White Tor is a typical epidiorite. The pale brown mica occurs in aggregates and the individual scales are somewhat larger than those of the Tolcarn rock represented in Fig. 2, Plate XVII. Sections at right angles to the basal plane are colourless when viewed with rays vibrating at right angles to the cleavage cracks and a pale brown when

viewed with rays vibrating parallel to these cracks. The interference colours are similar to those of muscovite. The tourmaline occurs in extremely irregular patches and aggregates. It is allotriomorphic.[1]

Rocks allied to the above, but frequently containing more or less original augite and therefore belonging to the proterobases, occur at various points round the granite-masses of Devon and Cornwall. They have been observed at Waspworthy, Brazen Tor and Cock's Tor near Tavistock; at the Sanctuaries, near St. Austell; at Tolcarn, near Penzance, and at St. Ives.

Where contact metamorphism has alone acted the only internal movement which has taken place is that dependent on the destruction of the old and the formation of new minerals in the rock and in veins. The ophitic augite is often represented by ophitic uralite and the ragged masses and skeleton crystals of iron-ore retain their form. There has been no mechanical deformation of minerals depending on a plastic deformation of the rock-mass. The rocks of Devon and Cornwall have, however, been profoundly affected by earth movements. The sediments have been folded and cleaved and the pre-granitic eruptive rocks have been subjected to the forces which produced the folding and cleavage. The consequent deformation of the rock-masses has been accompanied by interstitial movement and evidences of this remain in their macroscopic and microscopic characters. The most striking macroscopic feature is the development of schistosity and the most striking microscopic feature, apart from the mineral changes, is the development of a more or less definite parallel structure (foliation). It so happens that the regions where the mechanical forces have acted with the greatest intensity are in the immediate neighbourhood of great granite masses (*e. g.*, Penzance district) and consequently the two kinds of metamorphism (contact and dynamic) are superposed. This is, in all probability, not a mere accident; but a consequence of the fact that the intrusion of the granite-mass was connected with the earth-movements. It is, however, important to note that the relation of the granite veins, as for example those on the east side of Trewavas Head, to the clay slates is such as to show that the intrusion of the granite must belong to a very late phase of the earth-movement, for the veins traverse highly crumpled and cleaved beds without themselves being in any way affected by the contortions. The intrusion of the granite cannot possibly be regarded as the cause of the crumpling. It seems rather as if it marked the final relief of the intense stress to which the earth's crust had been subjected and brought about a state of equilibrium which, in this district, has not since been seriously disturbed.

Proterobases and epidiorites occur to a very great extent round the Land's End mass of granite near Penzance, Marazion, St. Just, Gurnard's

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(1) Prof. ROSENBUSCH proposes that a mineral should be said to be *idiomorphic* when it is bounded by crystalline faces peculiar to itself, and that when, owing to any cause, it is not bounded by characteristic outlines it should be said to be allotriomorphic. Thus in the Tolcarn rock (Fig 1, Plate XVII.) the tourmaline is idiomorphic.

Head and St. Ives. Not unfrequently they pass by imperceptible gradations into more or less foliated rocks Near the pier at St. Ives there occurs a very fine ophitic proterobase with traces of the effects of dynamic-metamorphism. The augite is pale in colour and passes into hornblende at the edges. The lath-shaped felspars have been more affected than the augites. They polarize as aggregates rather than as individuals. The slide is traversed by bands along which shearing has taken place so that the characteristic structure of the igneous rock has been partially destroyed. At Carack Olu, also near St. Ives, the metamorphism has been carried a stage further. A rock from this locality may be described as a foliated epidiorite. Traces, however, of the original ophitic structure remain. The foliation is not even and regular as in a typical schist, but of the flaser type. Ophitic epidiorites occur at many points in Cornwall. They have been observed at Gurnard's Head, Penlee Point, Marazion, Newham near Helston, and many other localities. There can be no doubt, therefore, that many of the highly metamorphosed rocks of West Cornwall were originally ophitic dolerites, essentially similar in structure and composition to those which occur in a comparatively unmetamorphosed condition at many points in East Cornwall and Devon. Nevertheless some of the rocks appear to have contained idiomorphic augite.

In addition to the more or less foliated rocks which can be definitely recognized as metamorphosed dolerites, Mr. PHILLIPS describes a number of slaty greenstones about the origin of which it is not possible at present to speak positively. Some of these resemble the metamorphosed dolerites in chemical composition; others differ from them in a remarkable manner. The former consist essentially of interlacing aggregates of actinolitic hornblende sometimes associated with a certain amount of chlorite, a colourless water-clear substance having the refraction and double refraction of quartz and felspar (probably in most cases secondary felspar) and more or less magnetite or ilmenite in a granular form. Garnet, tourmaline, and axinite are sometimes present as accessory constituents where the rocks occur near granite masses or large elvan dykes. The water-clear substance forms the matrix in which the hornblende is embedded. Examples of this class occur near Botallack, in the district between St. Erth and Camborne, and doubtless in many other localities. In chemical composition (see below) and also in specific gravity the rocks resemble the proterobases and epidiorites. They may be metamorphosed dolerites, basalts or basalt-tuffs.

The slaty greenstones which differ from the proterobases and epidiorites in composition have been recognized only in the Penzance district. They may be described as highly basic hornblende rocks. They are dark green in colour and frequently show a spotted aspect. Under the microscope the spots may be resolved into aggregates of interlacing actinolite, sometimes associated with a water-clear colourless mineral. The general mass of the rock is composed of hornblende, chlorite, granular opacite or leucoxene, epidote and a very small quantity of the colourless water-clear substance. The relative proportions of the above constituents

may vary considerably, but in all cases the ferro-magnesian minerals are present in much greater abundance than in the normal proterobases and epidiorites. The opacite or granular leucoxene often lies in bands which curve round the spots of interlacing actinolite. Under ordinary light the chlorite and hornblende cannot be easily distinguished; but under crossed nicols the distinction becomes easy as the former mineral gives only a dark blue shimmering light, whereas the latter polarizes in much higher tints. An important question arises as to the significance of the spots. Do they represent original vesicles?

Mr. PHILLIPS states that DE LA BECHE regarded these rocks as highly altered ash beds and remarks that it is not improbable that some of them may have been originally flows of volcanic mud. The rocks which run out to sea west of St. Michael's Mount (marked the Hogus on the map) appear to belong to this group, at any rate in part, and they are interesting as giving decided evidence of fragmental origin. Highly basic hornblende-slates of the above type occur at Paul Hill, Rose Hill near Castle Horneck, Chyandower near Penzance, and Rosemorran near Gulval. The following analyses by Mr. PHILLIPS illustrate the composition of the different types of "greenstone" above referred to.

PROTEROBASES AND EPIDIORITES.

	I.	II.	III.	IV.	V.	VI.
SiO_2	46·32	43·48	47·26	50·42	47·72	47·32
Al_2O_3	18·18	18·60	21·64	19·10	17·72	18·10
Fe_2O_3	·82	3·68	3·97	2·50	·60	6·21
FeO	10·92	11·38	8·92	11·03	10·71	7·72
MnO	tr.	tr.	tr.	·40	—	tr.
CaO	9·32	12·31	6·01	5·81	10·90	8·24
MgO	7·46	6·01	4·02	1·80	7·89	7·05
Na_2O	2·95	1·69	3·77	5·13	3·00	3·18
K_2O	2·07	1·12	1·91	1·67	·33	·62
P_2O_5	·52	tr.	·33	·74	tr.	tr.
FeS_2	·32	tr.	tr.	·43	—	—
H_2O	1·00	1·39	2·21	·98	1·03	1·90
	99·88	99·66	100·04	100·01	99·90	100·34
Sp. Gr.	3.02	3.01	2.98	2.97	3.04	2.90

I. Rock immediately north of St. Peter's Vicarage, Tolcarn. [Proterobase.]

II. Fine-grained crystalline rock from Tolcarn quarry.

III. Chapel Rock, west of Causeway leading to St. Michael's Mount. [Epidiorite.]

IV. Rock from the Sanctuary quarry near St. Austell. Also contains ·13 of lithia. [Proterobase.]

V. Trewint, near Five Lanes, north-east Cornwall. [Epidiorite.]

VI. Coarse grained crystalline rock from St. Cleer Down, south-east Cornwall. [Proterobase.]

FOLIATED ROCKS SIMILAR TO THE ABOVE IN COMPOSITION.

	I.	II.	III.	IV.	V.
SiO_2	50·57	48·30	46·89	46·57	52·54
Al_2O_3	19·65	17·04	20·46	19·50	23·83
Fe_2O_3	1·46	2·73	2·19	1·84	2·11
FeO	7·24	9·50	11·15	12·80	4·87
MnO	tr.	tr.	tr.	tr.	tr.
CaO	7·47	13·30	8·37	9·91	7·89
MgO	7·93	6·18	5·83	3·93	2·67
Na_2O	3·46	2·01	3·87	3·50	3·11
K_2O	1·08	·30	tr.	·51	1·95
P_2O_5	·12	tr.	·31	·63	tr.
FeS_2	tr.	tr.	tr.	tr.	—
H_2O	·74	·74	·97	·88	·63
	99·72	100·10	100·04	100·07	99·93
Sp. Gr.	2.89	3.03	3.03	3.02	2.89

I. Greenish grey rock from a quarry in the village of Newlyn, near Penzance.
II. Bluish grey slaty "greenstone" two miles W. of Camborne.
III. "Blue elvan" from Terrace about a mile and a half west of St. Stephen's Church.
IV. Compact greyish "greenstone" showing tendency to break into plates; North Huel Rose.
V. Green slaty rock from St. Cleer Down.

FOLIATED BASIC HORNBLENDE-ROCKS.

	I.	II.	III.	IV.	V.
SiO_2	37·44	35·58	39·20	36·57	37·72
Al_2O_3	16·32	21·14	16·22	15·34	17·19
Fe_2O_3	7·33	14·74	4·82	7·57	7·75
FeO	14·75	10·32	15·88	14·84	15·81
MnO	tr.	tr.	—	tr.	·43
CaO	12·83	9·20	10.70	12·58	14·00
MgO	6·06	2·78	6·56	5·98	3·41
Na_2O	1·85	2·11	1·45	2·99	1·06
K_2O	1·50	·95	2·69	1·44	1·02
P_2O_5	·27	tr.	·74	·68	·41
FeS_2	·23	tr.	—	—	tr.
H_2O	1·31	2·93	1·40	1·74	1·39
	99·89	99·75	99·66	99·73	100·19
Sp. Gr.	3.29	3.15	3.26	3.28	3.35

I. Paul Hill, Paul, near Penzance.
II. Rose Hill, Castle Horneck, near Penzance.
III. Chyandower, Penzance.
IV Rosemorran Gulval, near Penzance.
V. Pendower Cove, near St. Ives.

The more important facts described above may be summarized as follows:—

(1) Basic lavas and tuffs occur in association with Devonian strata.

(2) Rocks of the dolerite-type occur in a comparatively unmeta-

morphosed condition in East Cornwall and Devon. The most common rock is a normal ophitic diabase.

(3) Near the granite masses the diabases are represented by proterobases and epidiorites. Traces of an original ophitic structure are often preserved in the metamorphosed rocks.

(4) Tourmaline, pale brown mica and axinite are contact minerals.

(5) Diabases, proterobases and epidiorites often show traces of schistosity.

(6) This schistosity is mainly if not entirely the result of the post-Carboniferous earth movements.

(7) The proterobases and epidiorites do not vary very much in chemical composition or specific gravity.

(8) The foliated hornblendic rocks belong to two groups. The rocks of one group resemble the proterobases and epidiorites in composition and specific gravity, the rocks of the other group are more basic in composition, and possess a higher specific gravity.

The Lizard district is separated geologically from the rest of Cornwall by a line of disturbance running from Porthalla on the east to Polurrian on the west. We are not able at present to speak positively as to the age of the rocks occurring on the south side of this line, or as to the date of their metamorphism. In the eastern portion of the district between Porthoustock and Landewednack innumerable dykes of "greenstone" occur in the gabbro and serpentine. They appear, however, to be entirely absent from the hornblende-schist. In the south-western portion of the district there is a zone of intense mechanical metamorphism and in this zone we find lenticles and bosses of greenstone associated with actinolitic and hornblendic schists which owe their origin, in part at least, to the metamorphosis of the "greenstone." The dykes on the eastern coast have been described by Prof. BONNEY who arrived at the conclusion that "they were once all dolerites or basalts, and that the hornblende which undoubtedly characterizes many of them is a secondary product due to metamorphism of the pyroxenic original constituent."(1)

Subsequent research has merely tended to confirm this generalization, at any rate so far as the majority of the dykes are concerned. Macroscopically the rocks of these dykes are of a dark purplish or greenish colour and finely crystalline. They frequently contain porphyritic crystals of plagioclase. Granular and porphyritic specimens may, however, be obtained from one and the same dyke. Porphyritic augites have not been observed. When examined with the microscope the rocks may be classed as dolerites, proterobases and epidiorites according to the more or less complete replacement of the original pyroxene and olivine by secondary hornblende. In some of the dykes foliation has been superinduced by dynamic metamorphism, and in these cases the rocks may be described as foliated proterobases, epidiorites, or even hornblende-schists. Prof. BONNEY calls attention to a remarkable dyke occurring at the

(1) Q. J. G. S. Vol. XXXIII. 1877, p. 915

southern angle of the small beach in Caerleon Cove, about a stone's throw from the Poltesco serpentine works. "It is from 4 to 5 feet wide; the sides for about 6 to 10 inches are very dark and compact, and so platy in structure as to be almost undistinguishable from some specimens of the hornblende schists. This structure is lost rather suddenly; and the rock assumes the ordinary aspect of an igneous rock, consisting of a finely crystalline mixture of white felspar and dark hornblende with porphyritic crystals of the former as much as $\frac{1}{4}$ inch long." Under the microscope the ground-mass of the central portions of this dyke consists of pale green or brown hornblende, mostly fibrous (uralitic), felspar either turbid or water-clear and scattered grains of magnetite. The porphyritic felspars are turbid and have lost their individual action on polarized light. The relation of the felspar to the hornblende in the ground-mass leaves no doubt that the original rock was ophitic in texture. It is now an ophitic epidiorite. The rock from the margin of the dyke is principally composed of irregular grains of water-clear felspar, green hornblende and magnetite. A little turbid felspar giving lath-shaped sections is present in some slides and absent in others. *The micro-structure of the rock so far as it consists of water-clear felspar, compact hornblende and magnetite is that of a crystalline schist; not that of a normal igneous rock.* Apart from the direct evidence, furnished by the field relations, the occurrence of turbid lath-shaped felspars would give a clue as to the origin of the metamorphosed rock.

At Coverack and immediately to the north between this village and Manacle Point there occur dykes which have preserved their original characters to a remarkable extent. The least altered of these are ophitic olivine-dolerites. The augite is quite unaltered. It is almost colourless and occurs in fair sized masses, penetrated in all directions by the lath-shaped plagioclase. In one case distinct indications of micro-pegmatitic intergrowths of plagioclase and augite were observed in a slide which showed as a rule the normal ophitic character. The olivine shows no trace of serpentinization. It is, however, grey in colour in consequence of the presence of minute dust-like particles. With a magnifying power of 1,000 diameters some of the largest of these can be seen to be of a dark reddish brown colour. In some cases the particles are distributed uniformly through the mineral; in other cases they are aggregated in parallel bands. The olivines are also traversed by irregular cracks along which a segregation of magnetite has taken place. Their general appearance is represented in Fig. 1, Plate XVI. The lath-shaped plagioclase is colourless, brown or turbid. These conditions merely represent different stages of alteration and may be observed in one and the same individual. Turbid plagioclase forms only a very small portion of the entire mass. As a rule the mineral is as fresh as in many Tertiary dolerites. Irregular grains and crystals of magnetite are scattered through the slide and they are very often associated with a brown, uniaxial biotite. The biotite, however, never forms an important feature in the rock. It occurs as irregular scales. It is important to note that the iron ore does not occur in the form of large

skeleton rhombohedra (ilmenite ?) as in the ophitic diabases of Devon and East Cornwall. The rock described above appears to be in every respect identical with the "Ottfjäll-Diabas" of TORNEBOHM.[1] It differs from the other ophitic olivine-dolerites known to us in this country in the character of its olivines.

In the majority of cases the dykes in the eastern portion of the Lizard district must be described as epidiorites; in other words they consist essentially of plagioclase and secondary hornblende. The plagioclase may be either turbid or water-clear and the hornblende may be uralitic, actinolitic or compact. In a large number of cases the structure of the epidiorites is distinctly ophitic ; the lath-shaped felspars retain their original outlines and penetrate irregular masses of uralitic hornblende which correspond in form to the original ophitic augite. Iron ores occur in the epidiorites exactly in the same way as they do in the dolerites. The absence of olivine from the epidiorites is a noteworthy feature. The secondary hornblende is generally of a pale green colour; pale brown varieties may, however, be occasionally observed. That the epidiorite and dolerite dykes are of the same age is proved by the similarity in their mode of occurrence and by the fact that transitions may occasionally be observed from one rock to the other in the same dyke. The uralitization or amphibolization of the augite appears to be accompanied by the development of hornblende at the expense of the olivine. In some of the olivine-dolerites the olivines are seen to be surrounded by a narrow zone of a greenish mineral which possesses the double-refraction of hornblende and may probably be referred to that mineral.

Foliation has not been extensively developed in the dykes under consideration, but it occurs occasionally as, indeed, we have already mentioned. It is usually of the flaser-type, but sometimes we find the more even foliation characteristic of normal hornblende-schists. Sometimes the shearing movement has been concentrated, as it were, along certain planes which may be recognized in the thin sections; at other times it has been distributed over larger areas. Wherever it occurs the original microscopic structure of the rock has of course been more or less destroyed.

The south-western portion of the Lizard district is a region of intense mechanical metamorphism. The structural characters are similar in many respects to those which may be obtained along the great line of disturbance in the north-west of Scotland.[2] One type of rock very common in this highly metamorphic region is a green actinolitic or hornblendic schist. In association with this schist we find lenticles and bosses of epidiorite often distinctly porphyritic and having the forms of the original porphyritic crystals (felspars) well defined. These masses of rock, undoubtedly of

(1) N. J. 1877, p. 273.

(2) The resemblance between this district and the north-west of Scotland has been extended since this was written by MR. FOX's discovery of strong hornblendic gneisses with associated basic igneous rocks in the Islands off the Lizard Coast.

igneous origin, never take the form of dykes cutting through the schists but are associated with and sometimes pass into schists of similar chemical composition. The original relations of these masses of "greenstone" to the surrounding rocks have therefore been to a very great extent destroyed, and both the "greenstones" themselves and the surrounding rocks so metamorphosed that it is often difficult or impossible to determine their original characters. The most easily recognizable igneous rock in this district is a porphyritic epidiorite. The porphyritic crystals are now represented by white pseudomorphs, often half an inch in length, the forms of the originals having been perfectly preserved. These crystals appear as flattish tables with conspicuous development of the clino-pinacoid (010); the basal plane (001) and the prism faces (110 and $1\bar{1}0$) may also be recognized. In short, the crystals, or rather the pseudomorphs, have the forms characteristic of porphyritic dolerites. Under the microscope they are turbid and rarely show any traces of individual action under polarized light. They lie in a dark green ground-mass which is resolved under the microscope into an aggregate of water-clear plagioclase, uralitic and actinolitic hornblende and opaque iron-ore. The felspar of the ground-mass usually occurs in more or less lath-shaped forms but sometimes shows the mosaic structure. Quartz very probably occurs in association with this plagioclase, but has not been recognized with certainty. The ground-mass of this rock is exactly similar to the main mass of many of the epidiorites described by Mr. PHILLIPS from Western Cornwall. In addition to the porphyritic epidiorites above described we find also non-porphyritic rocks of a similar character. The lenticles and bosses of definitely recognizable igneous rock lie, for the most part, perfectly isolated in green actinolitic and hornblendic schists. Sometimes the boundary lines are tolerably sharp, at other times the external surfaces of the igneous rock are schistose and it is impossible to say where the massive rock ends and the schist begins. In studying the development of schistosity the porphyritic epidiorites are of great interest because the porphyritic crystals remain as more or less rounded "eyes" in the actinolitic schist. We will now describe one of these "augen-schists." Examined macroscopically the rock is a green satiny schist containing small white spots which sometimes show the outlines of felspars but are as a rule more or less lenticular in form. In thin section the ground-mass of the rock is seen to consist of very long actinolitic needles, water-clear felspar, iron ores and grains or crystals of rutile.[1] The pleochroism of the actinolite is well marked (a very pale green, β green, γ bluish green) but not so strong as that of the same mineral in the metamorphosed dolerites round the granite masses of Cornwall. The needles are arranged with their longest axes approximately parallel to each other in the plane of schistosity. Where the streams of actinolite needles en-

(1) In a paper, on the "Metamorphosis of Basic Igneous Rocks," by the author (Proc. Geol. Ass., Vol. X. p. 76), the rutile was erroneously described as sphene. It is highly probable that the rutile has been developed at the expense of the titaniferous iron-ores of the original rocks, whether directly or through the intervention sphene (leucoxene) it is difficult to say.

counter the white spots (turbid felspar) they sweep round them in graceful curves. The water-clear substance is certainly in many cases biaxial and therefore may be referred to felspar. It plays the rôle of ground-mass, and actinolite needles often project into or lie embedded in it. The "eyes" in the schist are composed of turbid felspar similar to that of the porphyritic epidiorites. In studying the green schists of the highly metamorphic zone in the south-west portion of the Lizard peninsula we meet with the usual difficulty of distinguishing between felspar and quartz, as both minerals are colourless and possess approximately the same refraction and double-refraction. The only satisfactory test, in the absence of form, and twinning, is the determination of the uniaxial or biaxial character of the grains by the use of convergent light. Quartz certainly occurs abundantly in some of the schists, but appears to be rare in those which can be definitely proved to have originated in consequence of the metamorphosis of igneous rocks. The exact nature of the water-clear felspar has not been determined. Reasoning from analogy we should expect it to be allied to albite. Mr. ADAMS[1] has described hornblendic and actinolitic schists, which seem to resemble in many respects those above referred to, from certain rocks of the Quebec group. The water-clear felspar in these cases gave a strong soda flame.

It is interesting to note the differences between the actinolite-schist from the south-western portion of the Lizard and the hornblende-schist which forms the margin of the Poltesco dyke. In the one case the hornblende is in the form of grains of nearly equal dimensions in the different directions, in the other case it is in the form of long acicular needles. As the original rock in both cases appears to have been similar in structure and composition the difference in the form of the hornblende is probably due to a difference in the conditions of metamorphism. On comparing the mode of occurrence of the two rocks it seems clear that the interstitial movement has been greater in the case of the actinolitic than in that of the hornblendic schists. The rocks above referred to are best studied in the neighbourhood of Polpeor and between that locality and Lizard Head. Everywhere along this portion of the coast the signs of intense mechanical disturbance are apparent.

One conclusion of general interest may be drawn from a study of the metamorphic phenomena in the south-western portion of the Lizard. We have seen that a clue to the origin of many of the green schists is given by the "eyes" or lenticles which these schists contain. According to the view we have adopted these "eyes" are portions of the original rock which have preserved their characters to such an extent as to allow them to be recognized. They are portions which, for some unknown reason, have escaped the intense metamorphic action. Now, if this view be correct, it will be found to be of widespread application. "Eyes" or lenticles of all sizes from microscopic dimensions to areas occupying many square miles on a geological map occur in regions of crystalline schists. It is to these

(1) Report of the Geol. Survey of Canada for 1882.

"eyes" or lenticles and their relations to the surrounding schists that we must look for a solution of many of the problems connected with the origin of the latter. It is proved that in many cases the schist is the result of dynamic metamorphism acting upon a rock having the composition of the "eyes," but the present state of our knowledge certainly does not warrant the assumption that this is invariably the case.

Malvern.—The central chain of the Malverns is composed of schists, gneisses and massive rocks, generally showing on the large scale more or less parallel structure. The last mentioned rocks often become basic in character by the excessive abundance of ferro-magnesian constituents especially hornblende. Some of the hornblende-schists are substantially identical in structure and composition with rocks known to have been formed by the metamorphosis of dolerites (diabases). Such rocks occur near the road side at Wind's Point. They consist of green hornblende (α, yellowish green; β, deep green; γ, bluish green) turbid and colourless felspar possibly associated with some quartz, granules of sphene with occasional kernels of iron ore and sometimes a little epidote. In some sections the forms of lath-shaped felspars can be recognized and also the forms of the original plates and skeletons of ilmenite.

In addition to the above rocks of more or less doubtful origin we find definitely recognizable igneous rocks of basic composition. These occur as dykes in the central chain and also in the adjacent Hollybush sandstone. The original rocks were dolerites and hornblende-dolerites. In their present condition they may be described as diabases, hornblende-diabases or as proterobases and epidiorites.

A typical ophitic diabase with ilmenite-plates and chlorite occurs as a dyke in the Hollybush sandstone between Eastnor Castle and Midsummer Hill. This is the type so common in the Lower Palæozoic rocks of North Wales and Ireland. A precisely similar rock occurs on the west side of Swinyards Hill. A rock from a quarry near the Wych is of the same general character. The augite is, however, in parts replaced by uralitic hornblende. This may be described as a uralitic diabase or proterobase.

Epidiorites in which the form of the ilmenite is often preserved occur on the east side of Swinyards Hill, at the south end of the east spur of Midsummer Hill, at the south-west end of Ragged Stone Hill, near the Wych and in the North Hill. In some of these a flaser structure has been developed by interstitial movement and in one case distinct planes of movement shearing the ilmenite plates was observed.

Ireland.—The sheets of igneous rock forming the plateaux in the north-east of Ireland are essentially similar in character to those of the west of Scotland. The dominant rock is an ophitic olivine-dolerite, similar in every respect to those represented in Fig 1, Plate IX., and Figs. 1 and 2, Plate X. Associated with these we find rocks of a more basaltic character containing minute lath-shaped felspars, granular augites and a variable amount of interstitial matter. At Carnmoney Hill, near Belfast, there occurs a rock which deserves more than a passing notice. It is an ophitic dolerite[1] with

(1) Olivine is not recognizable in the slide possessed by the writer.

interstitial matter. As a general rule the ophitic rocks are holocrystalline; the augite playing the rôle of ground-mass. In this rock, notwithstanding the presence of very large ophitic masses of augite with characteristic inclusions and penetrations of lath-shaped felspars, there is a considerable amount of interstitial matter. This consists of a brown isotropic glass containing rough rods of magnetite, feathery microlites of felspar and extremely fine acicular microlites, not capable of more precise definition. This rock fills a volcanic neck according to Professor HULL.[1] It contains the delessite-like mineral analysed by Mr. HARDMANN, and named by him Hullite.[2]

Basic lavas and tuffs occur at two horizons in the Carboniferous limestone of Limerick. They have been described by Mr. ALLPORT[3] and Professor HULL.[4] They are basaltic in character and bear the closest relation to the rocks of corresponding age in the midland valley of Scotland. In the least altered rocks the ground-mass consists of minute lath-shaped felspars, granules and crystals of augite and magnetite. Isotropic glass is occasionally present. In this ground-mass plagioclase, augite and olivine occur as porphyritic or micro-porphyritic constituents. The porphyritic augites sometimes show exquisite zonal banding (rock from Ballytrasma) and are honeycombed with inclusions. Mr. ALLPORT mentions the fact that a rock from Ballybrod contains small patches of red and green serpentine scattered through it. He says: "In one of the largest patches there are several grains of olivine; and an examination in polarized light shows very clearly that it was originally a nest of olivine which has been almost completely converted into serpentine." This is an extremely important observation because it is the only one yet made of the occurrence of anything like an olivine-nodule in any British basalt. Such nodules are extremely common in the Continental Tertiary basalts, as for example, those of the Rhine, and they have given rise to an interesting discussion. LEOP V. BUCH, BISCHOF, SANDBERGER, DAUBRÉE and more recently A. BECKER have maintained that the nodules are fragments or inclusions of rocks quite distinct from the basalt; ROTH, ROSENBUSCH and LASPEYRES, on the other hand, hold that they must be regarded as segregations from the basalt-magma. That the nodules in question are substantially identical in structure and composition with the true peridotites (lherzolites, saxonites and dunites) is admitted on all hands. Thus, olivine is the most important constituent and associated with this mineral we find enstatite, chrome-diopside and chromite or picotite. Advocates of the inclusion hypothesis rely on the fact that this association is not found in the normal basalt and also on the frequent resemblance, in form and relation to the basalt between the olivine-nodules and undoubtedly foreign inclusions such as fragments of granite, sandstones, &c. Advocates of the segregation

(1) Physical Geology and Geography of Ireland, p. 69.

(2) Nature, 1878, Vol. XVIII, p. 507. SiO_2 39·43, Al_2O_3 10·35, Fe_2O_3 20·72, FeO 3·69, CaO 4·48, MgO 7·47, H_2O 12·61, Total 99·77.

(3) Q. J. G. S., Vol. XXX., 1874, 552.

(4) G. M., 1873, p. 153.

hypothesis call attention to the similarity between the olivine of the nodules and that of the basalts and to the absence of similar nodules in the andesites and trachytes. BECKER and SANDBERGER reply that the absence is explained by the fact that the acid rocks have completely absorbed or dissolved the nodules by means of the excess of silica contained in the more acid magmas. In opposition to this it may be urged that perfectly angular inclusions of basalt occur in acid rocks (1) and this being the case there is no reason why inclusions of the ultra-basic rocks should not also occur. That the rocks of the olivine-nodules have been developed under plutonic conditions and not under the conditions that have given rise to the formation of basalt will probably be admitted by all advocates of the segregation hypothesis. Now we know that peridotites are constantly found associated with gabbros and that both rocks are formed in connection with the consolidation of basic magmas under plutonic conditions. This fact tells strongly in favour of the hypothesis which regards the nodules as being connected with the consolidation of the basic magma as against the alternative hypothesis which regards them as fragments wholly foreign to this magma.

The absence of olivine-nodules from the Tertiary basalts and dolerites of Great Britain, Ireland and Iceland is a striking feature and one which, together with the general absence of porphyritic augite and the frequent presence of the ophitic structure, seems to differentiate them from the Continental basalts of the same age. The nearest allies of the Continental basalts that we possess are some of the Carboniferous lavas of Scotland and Ireland. These contain porphyritic augites and, in the case of the rock from Limerick above referred to, nests of olivine-pseudomorphs which suggest the former presence of olivine-nodules.

The Limerick traps are often highly altered. One or more of the minerals, serpentine, chlorite, calcite and epidote, are almost invariably present. If we retain the term melaphyre for the altered basalts it may be conveniently applied to such rocks as those now under consideration.

The tuffs associated with the lavas are, as we should naturally expect, still more highly altered. They abound in vesicular lapilli, the vesicles now being filled with calcite. Fragments also of more compact micro-porphyritic rocks are not uncommon. Calcite is present in great abundance in the tuffs and may result in part from the decomposition of the original silicates. The bulk of it, however, has very probably been introduced into the rocks by waters percolating through the mountain limestone.

At Kilala Bay in Co. Sligo an east and west dyke occurs in the lowest members of the Carboniferous series. This is an extremely coarse grained dolerite with ophitic structure. The ophitic augite is completely subordinate to the felspar. It sometimes occurs as narrow plates between broad lath-shaped felspars. The rock has been described by Professor VON LASAULX.(2)

The augite is yellowish brown and slightly dichroic (a and γ yellowish

(1) See "Notes on the Rocks of St. Kilda," by A. Ross, British Ass. Report, 1885, p. 1040

(2) T. M. M. Neue Folge. Vol. I. (1878), p. 430.

brown, β with trace of red). It is associated with a brown mica. Iron ore is abundant, olivine rare. The augite contains glass inclusions and empty spaces which often take the form of negative crystals. This dyke is very probably of Tertiary age.

At Rostrevor, Co. Down, on the north side of Carlingford Lough, occurs a uralitic diabase (proterobase). It contains, according to Professor VON LASAULX, plagioclase, augite, uralite, viridite, magnetite and apatite. The felspar gives lath-shaped sections. The augite varies from reddish brown to colourless. It is altered at the margins into green fibrous uralite. The twin-planes of the augite can be followed into the uralitic aggregates. Sections approximately parallel to the clino-pinacoid of the augite give extinction angles, referred to the trace of the face of composition (100), of 37° in the augite and 10° in the uralite. The viridite (chlorite) is distinguished from the hornblende, which it resembles in colour, by its feeble double-refraction. The rock is termed a eucrite by Professor VON LASAULX. Two specimens of the same type of rock from Rostrevor have been examined by the present writer. Uralite is not conspicuous in either of them, quartz and epidote occur in one, a feebly polarizing and feebly pleochroic chlorite in both. The ophitic structure is most pronounced, and the iron-ore occurs in the large ragged plates so characteristic of the older diabases. These two specimens are identical in every respect with the non-olivine bearing ophitic diabases of Wales, Devon and Cornwall.

The "greenstones" of the Island of Lambay are intrusive in lower Palæozoic strata. The best known is the so-called Lambay Porphyry. This rock has been described in detail by Professor VON LASAULX. Macroscopically it consists of conspicuous plagioclase crystals, now generally of a pale greenish tint, embedded in a dark green compact matrix. The porphyritic plagioclase crystals are as a rule so much altered that the twin striation is unrecognizable.

The ground-mass of the rock contains, according to VON LASAULX, minute lath-shaped felspars, viridite, epidote, sphene, leucoxene, magnetite, pyrite and calcite. Viridite (chlorite) is the most prominent constituent. In some cases augite may be distinctly recognized and its relation to the viridite is such as to show that the latter mineral must be regarded as its alteration product. The general alteration to which the rock has been subjected makes it difficult to say whether any interstitial matter originally existed. The rock is termed diabase-porphyrite by VON LASAULX and ROSENBUSCH.

Basic igneous rocks occur in the Lower Palæozoic region of Wicklow, Wexford and Waterford. Some of these are perfectly typical ophitic diabases (dolerites with chlorite, epidote, leucoxene, and other alteration products) with large skeletons of titaniferous iron-ore. They exactly resemble the corresponding rocks of North Wales, Devon and East Cornwall. Good examples of this type occur at Rathdrum, Co. Wicklow, Tintern Bridge, Co. Wexford, and near the town of Waterford. Professor VON LASAULX mentions the occurrence of a diorite about half-way between Rathdrum and Avondale Castle. The rock shows rough columnar jointing

and is almost compact in texture. It is green in colour and contains epidote in veins and radial groups. The hornblende is described as fibrous (schilfig oder faserig). This raises the presumption that the rock is not a true diorite, but an epidiorite.

Some very remarkable rocks which may be referred to in this connection occur at Carrigmore, Co. Wicklow. The following description is based on specimens in the ALLPORT collection in the British Museum. One section shows large ophitic plates of an intensely dichroic biotite, with numerous inclusions of apatite, a pale coloured pyroxene with brownish inclusions parallel to the ortho-pinacoid and basal plane (pseudo-hypersthene) aggregates of water-clear plagioclase (compare Fig. 1, Plate VIII.) with green infiltration products along cracks and the boundaries of the individual grains, greenish fibrous pseudomorphs which may represent enstatite and a few grains of opaque iron-ore. The pyroxene individuals are often twinned parallel to 100, and when this is the case the characteristic herring-bone lineation, due to inclusions parallel to 001, is seen in sections more or less parallel to 010.

The section of another rock from the same locality is still more remarkable. This section consists of biotite, a monoclinic pyroxene, plagioclase, apatite, and magnetite, exhibiting the same characters and relations to each other as in the above; but it contains in addition large grains of olivine and smaller grains of a feebly but distinctly pleochroic pyroxene. The olivine in some cases contains parallel rows of inclusions and irregular cracks along which there has been a great deposition of magnetite; indeed most of the magnetite in the rock is present in the olivine. The substance of the olivine is perfectly fresh. The pleochroic pyroxene is also fresh and contains no inclusions; unfortunately the grains are so irregular and the cleavages so faintly indicated that it is impossible to determine the system of crystallization. The pleochroism (reddish and greenish tints) favour the idea that it is a member of the enstatite group This pyroxene exhibits a decided tendency to form zones round the olivine, reminding one of the zoned olivines described by Mr. ADAMS, from the Saguenay river. There is, however, no actinolite border outside the border of pyroxene, and in this respect the case is similar to one observed by the author in a gabbro from the Lizard. Those authors who lay stress on the diallagic condition of the pyroxene will of course term these rocks gabbros.

The basic igneous rocks in the metamorphic districts of the west and north-west of Ireland have not yet received much attention at the hands of modern petrographers. The facts described by Mr. TRAIL in the Explanatory Memoir to accompany sheets 39, 40, 51 and 52 of the Geological Survey of Ireland seem to show that they are of great interest from the point of view of metamorphism. They occur as sheets and dykes in Western Mayo and belong to two periods, pre-Carboniferous and post-Carboniferous (probably Tertiary) Mr. TRAIL says :—"There is a general resemblance between the rocks of each of these groups, for they both belong primarily to the pyroxenic division. . . . The older series, to a large extent,

occurs chiefly in sheets among the mica-schists and quartzites, contorted and crumpled with them, and often apparently resembling only altered beds of the metamorphic series. Their intrusive nature, in most cases, may however, be determined on careful examination by the cutting across of some beds in part of their course. . . . These sheets and dykes, for the greater part, seem to have been intruded among the sedimentary strata, from which the metamorphic rocks have been formed, previous to the occurrence of the metamorphic action, and to have been displaced, contorted and themselves metamorphosed with these beds. . . . . It is of frequent occurrence to find in thick sheets of this trap that the central portion is apparently a micro-crystalline basalt (melaphyre), passing by imperceptible gradation into a fibrous hornblendic rock, and this again, towards the margin of the sheet, into a black micaceous schistose mass in platy layers, conforming to the bedding of the adjacent mica-schists. . They [the rocks] are composed of plagioclase, the triclinic characters of which are clearly visible, and a pyroxenic mineral which—probably owing to the metamorphic action—is variable, augite, hornblende, and diallage graduating into each other. Green chlorite seems also to be largely present, in fact to form almost an essential."

In the absence of detailed petrographical descriptions it is impossible to speak positively as to the characters of the above rocks. It seems probable, however, from the above descriptions that we have here illustrations of the development of hornblendic and chloritic schistose rocks in consequence of dynamic metamorphism operating upon intrusive sheets. The date of the dynamic metamorphism has not been actually determined. It was certainly pre-Carboniferous because pebbles of the metamorphosed rocks occur in the basement Carboniferous conglomerate. The general strike of the metamorphic series (mica-schists, quartzites, etc.) in which the igneous rocks occur is approximately N. and S. It seems probable therefore that the metamorphism is of the same age as that of the north-west of Scotland post-Ordovician).

So far we have been referring to rocks in which the dominant ferromagnesian constituent either is now or was originally some variety of pyroxene. We have, in the next place, to refer to basic rocks in which hornblende plays an important part as an original constituent. Such rocks are usually termed diorites. Some of the more granitoid rocks have been termed hornblende-gabbros.

Basic plagioclase-hornblende rocks have been recognized in Leicestershire, Warwickshire, Anglesea, the Lake District and the Highlands of Scotland. The Warwickshire rocks were described by Mr. ALLPORT[1] in 1878. They vary considerably in texture, mineralogical composition and state of preservation. They are associated with Cambrian strata into which they have been intruded, mostly in the form of sheets. The original hornblende of these rocks occurs as well defined brown prisms or as deep brown ophitic masses, often giving rise to green and even colourless

(1) Q. J. G. S. Vol. XXXV. p. 637.

hornblende by alteration. The idiomorphic prisms show the clinopinacoid (010) as well as the ordinary prism faces and lie in a matrix of felspar (see Fig. 2, Plate XXIX). The ophitic masses are, on the other hand penetrated by lath-shaped felspars in the same way as ophitic plates of augite (see Fig 1, Plate XXIX). We have direct evidence, therefore, that in some of these rocks the hornblende preceded, and in others succeeded the felspar. The ophitic character is especially noticeable in those rocks which contain a large amount of hornblende. All that has been said with reference to the hornblende of the picrites (see *ante* p. 90) will apply to the hornblende of these rocks.

The plagioclase of the least altered rocks is perfectly fresh and shows the characteristic twin lamellation. In the altered rocks, which are by far the most numerous, turbid plagioclase occurs and the mineral is often represented by pseudomorphs which have lost all individuality. Iron-ores and apatite are invariably present and the latter mineral is often very abundant. A nearly colourless pyroxene and pseudomorphs after olivine may or may not be present. Calcite frequently occurs in considerable quantity especially in the olivine pseudomorphs. The highly altered condition of many of the rocks often makes it very difficult to determine their original characters.

In texture the rocks vary from coarsely crystalline to compact. The large ophitic plates of hornblende in the former are sometimes very conspicuous and characterized by the lustre-mottling already referred to in describing the picrites. The finely crystalline and compact rocks resemble dolerites and basalts in general aspect. Rocks with idiomorphic hornblende were observed by Mr. ALLPORT at Marston Jabet. They occur also in the Tuttle Hill quarry, near Nuneaton. Allotriomorphic (ophitic) hornblende is more common. It occurs in rocks from Atherstone Outwoods Purley Park, Chilvers Coton and doubtless many other localities. Olivine-augite-hornblende-plagioclase rocks occur in the neighbourhood of Atherstone and especially in Purley Park. Associated with the above hornblende-bearing rocks we find others (*e.g.*, specimens from the large quarry close to one of the Nuneaton railway stations) which appear to be altered plagioclase-pyroxene rocks (diabases).

Plagioclase-hornblende rocks often containing a certain amount of colourless pyroxene occur at Brazil Wood near Mount Sorrel in Leicestershire, at Little Knotts near Keswick, in the Lleyn Peninsula of Caernarvonshire and in Anglesea. As already stated they pass into hornblende-picrites by a decrease in the amount of felspar and an increase in the amount of olivine. They are also intimately related to the dolerites (diabases) and the hornblende-dolerites or -diabases may be regarded as the connecting links.

Dr. HEDDLE[1] refers to some remarkable rocks occuring in Banffshire. A rock occurring west of the Battery at Portsoy is composed of labradorite and hornblende together with a certain amount of ilmenite, sphene and a

(1) Trans. Roy. Soc. Edin. Vol. 28. Chapters on the Mineralogy of Scotland. Parts I. and II.

dark brown mica. Both the felspar and hornblende of this rock have been analysed. The rock forms part of a large mass (3 by 14 miles) which is stated by Dr. HEDDLE to vary greatly in composition. In some portions of the mass the principal ferro-magnesian constituent is augite, in other portions hornblende and in others biotite. This mass forms the "syenite" of Hay Cunningham. Labradorite appears to be the dominant felspar. Dr. HEDDLE also describes a labradorite-hornblende rock occurring on the north side of Glen Bucket in which the crystals of hornblende occasionally attain gigantic dimensions (21 inches in length by 2 in breadth) and an anorthite-hornblende rock from Trista in Fetlar, one of the islands of the Shetland group.

In dealing with the plagioclase-hornblende rocks the artificial character of our system of classification is admirably illustrated. Quartz-diorites of intermediate composition shade into basic plagioclase-hornblende rocks by the most insensible gradations. Some of the more crystalline rocks from the Assynt district of Sutherland which we shall describe in the next chapter because they are associated with normal hornblende-porphyrites, contain a smaller amount of SiO_2 (52 to 54 p. c.) than the rocks already described as andesitic dolerites.

CHAPTER VIII.

GROUP B. INTERMEDIATE DIVISION.

Nomenclature.

THE rocks of this division are distinguished from those of the preceding by their specific gravity and composition. The specific gravity of the holocrystalline members lies generally between 2·7 and 2·8 and the silica-percentage between 55 and 65 The ferro-magnesian constituents play a less important part than in the rocks of the basic division. It is, however, quite impossible to give any precise definition of the group. The basic rocks shade into the intermediate rocks, and these again into the acid rocks, in the most gradual manner.

Various names such as diorite, tonalite, banatite, propylite, quartz-norite, trachy-dolerite, andesite, porphyrite, have been applied to different members of the group. Some of the rocks to which the term granite has been applied must be regarded as belonging to this rather than to the acid division; especially some of the hornblende- and augite-granites.

Diorite.—The history of this term has been briefly referred to on p. 133. It cannot be said to have at present any very definite signification. Almost all writers agree that a rock must be holocrystalline in texture and must contain a plagioclase felspar in order to justify the application to it of the term diorite, but beyond this there is no general agreement. The ferro-magnesian constituent may be biotite, hornblende, augite (diallage), enstatite (hypersthene) or mixtures of these in varying proportions. Many of the rocks to which the term augite-diorite has been applied, including some of the typical augite-diorites described by Streng from Minnesota, are basic in composition. Precisely similar rocks occurring near Baltimore have recently been described by G. H. Williams as gabbros. It appears therefore that, as at present used, the term diorite has only the vaguest possible signification. Metamorphosed gabbros and dolerites, unmetamorphosed gabbros (augite-diorites) and plagioclase rocks containing original hornblende and belonging to the basic and intermediate groups have all been termed diorites. Some order will be introduced into this chaos if we separate altogether the basic rocks with secondary hornblende from the diorites, under Gümbel's name epidiorite.

This we have already done. Can we give any further precision to the term diorite?

Now it will not be denied that we want a general term for the plutonic rocks of intermediate composition; that is for the hypogene representatives of the andesites. Of the terms available diorite seems the most suitable, and so far as possible we shall employ it in that sense. It must be remembered, however, that it is also used for basic rocks containing original hornblende. When these are spoken of they will always be referred to as basic diorites; or, if they contain olivine, as olivine-diorites. They appear to be unimportant when compared with the other representatives of the basic group; and it is a question, after all, whether they might not be more suitably named hornblende-gabbros and hornblende-dolerites.

Leaving out of account, then, the basic plagioclase-hornblende rocks we may roughly define diorite as the plutonic representative of the andesitic magma; just as we defined gabbro as the plutonic representative of the basic magma. The different varieties of diorite may be more accurately defined by reference to the nature of the ferro-magnesian constituent. The best marked types are the following:—

AUGITE-DIORITE, *e.g.*, certain rocks occurring near Carrock Fell already referred to as quartz-gabbro.

ENSTATITE-DIORITE, *e.g.*, rock extensively quarried near Penmaenmawr.

HORNBLENDE-DIORITE, or Diorite proper, *e.g.*, intrusive rock of Glen Tilt (in part).

MICA-DIORITE, *e.g.*, certain rocks occurring at the Lizard.

As quartz is probably always present in the plutonic rocks of intermediate composition, it seems scarcely desirable to separate the rocks under consideration into quartz-diorites and quartz-free diorites except in the case of the hornblende-bearing diorites. Thus, the quartz-free augite-diorites are gabbros, and the quartz-free enstatite-diorites are norites. Mica-plagioclase rocks of normal basic composition do not appear to have been recognized. The mica-traps form an exceptional group of rocks and will be considered by themselves.

One important argument in favour of the above scheme is that it brings the nomenclature of the plutonic rocks into direct relation with that of the volcanic rocks. Augite-diorite corresponds to augite-andesite, enstatite-diorite to enstatite-andesite, hornblende-diorite to hornblende-andesite, and mica-diorite to mica-andesite. In considering this relation it must always be remembered that the quartz-free andesites have their plutonic representative in quartz-bearing rocks. In the andesite the silica is present in the interstitial matter; in the holocrystalline rock it separates out as quartz.

Tonalite.—This name was applied by VON RATH in 1864 to the rock which forms the mass of Monte Adamello, south of Tonale, in the eastern Alps. It consists of plagioclase, quartz, magnesia-mica, and hornblende. Orthoclase is present only in very small quantity. The felspar was analysed and found to lie between labradorite and andesine—(oxygen-ratio

1 : 3 : 7; Na_2O, 6·10; K_2O, 0·34; Sp. Gr. 2·69). Bulk analysis—SiO_2 66·91 Al_2O_3, 15·20; FeO, 6·45; MgO, 2·35; CaO, 0·73; Na_2O, 3·33; K_2O, ·86; H_2O ·16; total 98·99; Sp. Gr. 2·724. The rock is thoroughly granitic in texture. The specimen analysed contained a large amount of quartz. Professor BONNEY[1] has proposed that the name tonalite should be used generally instead of quartz-diorite.

Banatite.—This name was applied by VON COTTA to certain rocks occurring in the province of Banat in Hungary. They are intrusive in rocks as late as the Cretaceous. Similar rocks occur in the Schemnitz district.[2]

The Schemnitz rocks have been variously termed greenstone-trachyte, syenite, diorite and propylite by different authors. According to ROSENBUSCH they vary in character between quartz-diorites (tonalites), quartz-augite-diorites, diorites and augite-diorites. Quartz is generally present; the amount of augite varies in different specimens from one and the same locality. The hornblende is either brown or green. The biotite in its original condition is always brown, but owing to alteration it is frequently seen to consist of alternating brown and green layers. Hypersthene is occasionally present. The plagioclase belongs to the andesine-labradorite series. It contains glass and liquid inclusions. The quartz is rich in liquid inclusions. Sphene and zircon occur as accessories; epidote, calcite and uralitic hornblende as secondary constituents. Owing to alteration the rocks assume the so-called propylitic or greenstone-like aspect. They have a silica percentage of from 60 to 65, and a specific gravity varying from 2·6 to 2·7. In structure, composition and mode of occurrence they may be regarded as typical diorites in the sense in which that term is employed in the present work; in other words they are the hypogene representatives of the mica-, hornblende- and augite-andesites.

Propylite.—This name was introduced by RICHTOFEN for rocks of the above group occurring near Schemnitz and was subsequently extended by him to similar rocks occurring in the Washoe district of North America. It was believed for some time that these rocks were the earliest eruptive rocks of the Tertiary period and considerable interest attached to them on that account. It is now generally recognized that this view was incorrect and the term propylite has almost disappeared from petrographical literature. The special features of the group are now recognized as being due partly to the conditions of consolidation (plutonic) and partly to subsequent alteration.

Quartz-norite.—A very interesting group of eruptive rocks of intermediate composition occurs in the neighbourhood of Klausen in the Tyrol. They are well exposed in the valleys of the Tinnebach and its tributaries the Rothbach and the Vildar. The general term diorite has been used for these rocks. TELLER and VON JOHN [3] have shown that they are composed essentially of plagioclase, hypersthene, enstatite, augite (including diallage), biotite, quartz, magnetite and apatite. The felspar gives lath-shaped sections.

(1) Q. J. G. S., Vol. XLI., Proc. p. 73.
(2) See JUDD on the ancient volcano of the district of Schemnitz. Q. J. G. S., Vol. XXXII. (1876), p. 292.
(3) J. G. R., 1882, XXXII., p. 589.

In chemical composition it is intermediate between andesine and labradorite. Hypersthene occurs in brownish-red grains and crystals. The pleochroism and other optical characters may be determined in those sections which show crystalline form. The enstatite is distinguished from the hypersthene by the absence of colour. Both minerals frequently show the characteristic alteration to bastite. Diallage and augite occur in irregular grains. These minerals are often intergrown with hypersthene and biotite. Biotite occurs in irregular plates of reddish brown colour, which show a most intense pleochroism. It changes into a green chloritic mineral throughout which yellow epidote grains are usually scattered. Quartz is almost if not always present, but varies in amount in different specimens. It occurs in grains and granular aggregates, but never shows good crystalline outline. It contains fluid inclusions and occasionally grains of augite and small plates of biotite. It is sometimes intergrown with felspar in the form of micro-pegmatite and in some of the more acid rocks the micro-pegmatite forms a kind of ground-mass. Magnetite occurs in grains and is often attached to biotite in which it always occurs as inclusions. Apatite is especially abundant in the rocks which contain much quartz. It occurs in the form of very long thin needles. The authors separate the rocks into four principal groups which, however, are connected by intermediate forms. They propose the following names for the four groups :—(1) Norite, (2) Quartz-norite, (3) Norite-porphyrite, (4) Quartz-mica-diorite. These groups are defined by the relative proportions of the different constituents and by the presence or absence of porphyritic constituents. Quartz is present in all of them, but is less abundant in the norites than in the other members of the group. It will be observed that the presence of quartz in the norites of TELLER and VON JOHN separates these rocks from the typical basic norites. In fact these quartz-bearing norites bear the same relation to ordinary norites that the quartz-gabbros of Carrock Fell do to ordinary gabbros. The norites and quartz-norites occasionally become porphyritic by the conspicuous development of plagioclase and a rhombic pyroxene. Orthoclase may sometimes be observed in porphyritic crystals. By an increase in the amount of biotite and a decrease in the amount of pyroxene the rocks of the norite-group pass into pyroxene-bearing quartz-mica-diorites and finally into typical quartz-mica-diorites. These are the most acid members of the group.

The following analyses illustrate the composition of the group :—

	I.	II.	III.	IV.	V.
SiO_2	55·80	56·85	59·97	64·12	70·17
Al_2O_3	17·20	16·70	16·93	16·50	11·10
Fe_2O_3	5·22	5·92	2·41	2·71	1·92
FeO	7·13	7·13	4·83	4·26	2.86
CaO	6·97	5·97	5·10	4·76	3·34
MgO	2·76	3·25	3·61	2·34	1·23
K_2O	1·23	1·91	1·32	1·92	3·23
Na_2O	3·62	2·78	3·87	3·92	3·77
Loss	1·23	0·54	1·60	0·73	1·87
	101·16	101·05	99·64	101·26	99·49

I. Fine grained norite from the Tinnebach.
II. Typical norite from Oberhofer.
III. Quart-norite from the Vildarthal.
IV. Quartz-norite between Johannser and Muttler Hof.
V. Quartz-mica-diorite from the Vildarthal.

The first four rocks may be regarded as typical enstatite-diorites or rather as typical enstatite-augite-diorites. We have described them somewhat fully because they closely resemble the "diorite" or "enstatite-diabase" of Penmaenmawr and because they must be regarded as the hypogene representatives of such rocks as the Cheviot enstatite-augite-andesites.

Andesite.—This name was introduced by L. VON BUCH for rocks which had been previously classed with the trachytes under the impression that the dominant felspar was sanidine. Like almost all other names in petrography it has been so variously used by different writers that it has almost ceased to have any definite significance. If we define andesite as the volcanic representative of the intermediate magma we shall find that it will correspond very closely with the common use of the term.

The lavas of the Andes furnish typical examples of andesites, as indeed the name implies. Precisely similar rocks are found all round the Pacific "circle of fire," in Central America, the west of North America, Japan and the islands of the East Indian Archipelago.

The andesites are distinguished from the trachytes which they requently resemble in general aspect by the predominance of a plagioclase-felspar—labradorite, andesine or oligoclase. The so-called oligoclase-sanidine trachytes may be regarded as intermediate between andesites and trachytes. The majority of the andesites are porphyritic rocks in which both felspar and a ferro-magnesian constituent occur as porphyritic elements.

In some rocks which have been termed andesites original quartz also occurs. These are as a rule acid rocks and will be described in the present work under the general term *dacite*. The quartz-free andesites may be conveniently subdivided into groups according to the nature of the ferro-magnesian constituent. We thus have:—

AUGITE-ANDESITE.
ENSTATITE-ANDESITE,
HORNBLENDE-ANDESITE.
MICA-ANDESITE.

In most cases more than one ferro-magnesian constituent is present. These can, however, be always designated by using compound names such as enstatite-augite-andesite.

Dr. SZABO does not recognize the term andesite. He uses the general term trachyte to cover not only the orthoclase-bearing lavas but also those in which plagioclase is the dominating felspar.

When the porphyritic plagioclase has been determined its name may also be introduced. We may thus build up compound terms which are in reality concise descriptions of the rocks. In the vast majority of cases the rocks termed andesite are distinctly porphyritic. This rule is so general that

whenever the term andesite is used in the present work it may be taken to imply a porphyritic texture unless the contrary is stated. Another feature equally characteristic of the andesites is the presence of interstitial matter, either cryptocrystalline, microfelsitic or vitreous. The interior of massive lava flows may become holocrystalline. Then, of course, we have rocks undistinguishable from the hypogene representatives of the same magma (diorite) and the artificial character of our system of classification is exposed.

The analyses of the diorites of Klausen already quoted may be regarded as representing in a general way the composition of the andesites.

Trachy-dolerite.—This name was introduced by ABICH (1) for volcanic rocks of intermediate composition. The silica-percentages of the rocks analysed by ABICH range from 57 to 62. The term andesite has now replaced the term trachy-dolerite. Mr. WARD proposed the term felsi-dolerite for certain rocks of the Lake District which resemble the trachy-dolerites of ABICH in composition. These rocks are simply altered andesites and may therefore be appropriately termed porphyrites.

Porphyrite.—A study of the literature does not enable one to attach any very definite signification to this term. It has been applied to rocks of intermediate and basic composition and even to rocks in which orthoclase is the dominant felspar. The name porphyrite seems to imply a porphyritic texture; but it has been extended so as to include non-porphyritic rocks. If we define porphyrite as a pre-Tertiary andesite (usually more or less altered) we shall include most of the rocks to which the term has been applied by Continental authors. If we decline to recognize geological age as a factor in petrographical classification we can give some precision to the term by defining it as a more or less altered andesite. A difficulty arises, however, when we endeavour to apply this definition because the term has occasionally been extended to basic rocks. A partial solution of the difficulty would be found if petrographers would agree to call the basic rocks melaphyres (altered rocks of basaltic composition). It is not possible to remove all difficulty because of the existence of intermediate forms.

In what follows we shall use the term porphyrite for the more or less altered andesites. In this sense typical porphyrites occur in the Lake District and in the Cheviot District. In the latter they are associated with unaltered andesites. COTTA places the porphyrites with the plutonic rocks. The typical porphyrites are unquestionably lavas. They are frequently amygdaloidal and are often associated with tuffs.

The subdivisions of the porphyrite-group correspond exactly with those of the andesites. We recognize enstatite-, augite-, hornblende- and biotite-porphyrites. The pyroxene-porphyrites (porphyrites with enstatite or augite) are the most basic members of the series and the biotite-porphyrites the most acid; the associated porphyritic felspar of the former is often labradorite; that of the latter oligoclase. A rock from Eycott Hill has already been referred to as a labradorite-pyroxene-porphyrite; one

(1) Geologische Beobachtungen über die vulkanischen Erscheinungen, &c. Brunswick 1841.

occurring at Canisp[1] in Sutherlandshire may be regarded as a typical oligoclase-biotite-porphyrite.

The mica-traps must not be confused with the normal mica-porphyrites. They constitute a portion of a somewhat exceptional group of rocks —the lamprophyr-group of GÜMBEL and ROSENBUSCH—and will be described in another chapter.

CHARACTERS OF THE ROCK-FORMING MINERALS.

Felspar.—Two generations of felspar are almost always recognizable in the andesites; in the granular diorites only one generation is present as a rule. The felspars of the first generation in andesites are generally either labradorite, andesine or oligoclase; bytownite and even anorthite have, however, been recorded. They are frequently somewhat tabular in form with conspicuous development of the brachypinacoid. Glass inclusions and inclusions of the ground-mass are very common. These inclusions may be scattered irregularly through the crystal; more frequently they occur in greater abundance either in the centre or near the margin; and not seldom they are found to be arranged in a number of concentric zones. Inclusions of the ferro-magnesian constituents and iron-ores also occur in the felspars. A zonal structure due to a variation in the optical properties of successive layers is by no means uncommon. Very often the felspars have been broken by interstitial movements which have taken place in the magma subsequent to their development. Twinning on the albite plan may almost always be observed and very frequently this is associated with twinning on the Carlsbad and pericline plans.

The felspars of the ground-mass occur in small columnar forms giving lath-shaped sections. The direction of elongation is that of the edge 010 : 001. These felspars sink to the smallest dimensions (microlites) and are often so numerous as to produce a kind of felt-like aggregate—the "mikrolithenfilz" of German authors. In composition they appear to be always more acid than those which occur as porphyritic constituents. Thus, M. FOUQUE has shown that in a pyroxene-andesite from Santorin, the porphyritic felspars are labradorite and the microlites of the ground-mass albite. Microlites giving nearly straight extinction in all longitudinal sections (oligoclase) are common in many andesites. The felt-like aggregate of felspar microlites may, in a certain sense, be regarded as the characteristic feature of the andesites. It is very rarely observed in the volcanic rocks of basic or acid composition.

In the plutonic rocks of intermediate composition the plagioclase belongs as a rule to only one period of consolidation and the crystalline form is rarely so well shown as in the porphyritic crystals of the volcanic rocks. Liquid and gas inclusions are present, but glass inclusions are comparatively rare. Orthoclase is frequently present and by an increase in the amount of this constituent the diorites shade so gradually into the granites that it is often impossible to say to which class a given rock

(1) Some portions of the Canisp mass contain orthoclase, often zoned with oligoclase.

should be referred. A micro-pegmatitic intergrowth of quartz and felspar is often recognizable in the diorites. It is generally assumed that the felspar so intergrown is orthoclase; but this is certainly not always the case.

In the altered rocks the felspar is generally more or less turbid and very frequently it has been so changed as to have lost its distinctive optical character. It is in many cases impossible to determine the nature of the extremely minute granular or scaly substances which produce the cloudiness; in some cases, however, a white mica may be seen to arise in consequence of the alteration of plagioclase. When, as frequently happens, the alteration of the felspar is accompanied by that of the other constituents of the rock chlorite, epidote, calcite and limonite may be produced.

Quartz.—This mineral is sparingly present in the diorites, at least in the form of an original constituent. It occurs as irregular grains filling up the interstices between the other constituents and also as a constituent of micro-pegmatite. Silica also occurs in the form of tridymite, opal, hyalite, chalcedony or jasper in the andesites. Tridymite occurs in the form of overlapping hexagonal tablets in the more or less open spaces. Opal and chalcedony in veins and also disseminated through the mass of the more porous rocks. Professor VON LASAULX and Dr. HATCH have shown that the high percentage of silica in certain andesites is due to the impregnation of the original rocks with secondary silica. In deciding on the position of a rock from the bulk analysis it becomes of the greatest importance to determine whether any silica has been introduced.

Hornblende.—In the andesites this mineral occurs as one of the porphyritic constituents. The usual forms in the vertical zone are those of the prism (110) and clinopinacoid (010); less frequently we find these in combination with the orthopinacoid (100). Twinning is not uncommon. The colour in ordinary light may be brown, yellow, orange or green. One very common and interesting feature is the presence of a zone of magnetite granules round the external boundaries. This zone is due to the action of the magma on the crystals. In some cases the hornblende crystals are represented by pseudomorphs of magnetite which retain the form of the original mineral; in others they are represented by dark patches in which only obscure traces of the form of the hornblende can be detected. Good illustrations of these phenomena may be observed in the hornblende-andesite (porphyrite) of Ben Nevis. VON LASAULX,[1] OEBEKE[2] and others have observed microlites of secondary augite associated with the granular magnetite in the zones surrounding certain hornblendes.

That the magnetite zone, with or without augite microlites, is the direct result of the action of the magma on the enclosed crystals has been demonstrated experimentally by DOELTER and HUSSAK[3] who have produced it artificially. It is quite clear therefore that the hornblende crystals in

(1) Der Etna. Leipzig (1881), II., 484

(2) N. J. (1881.) Beilage Band I., 474.

(3). N. J. 1884, Band I., 25.

andesites are, at the time of the eruption, in what may be termed a state of unstable equilibrium. They are liable to be dissolved by the magma and to give rise to other minerals by a rearrangement of the molecular groups.

An important question arises as to whether they are the products of the consolidation of the magma before eruption or whether they must be regarded as altogether foreign to the magma. The former appears to be the more probable supposition.

The hornblende of the diorites may occur as more or less perfect crystals of the usual form or as grains. In the so-called needle-diorites of GÜMBEL it occurs in long prisms. In colour it is either green or brown. A zonal structure is sometimes present. By alteration it gives rise to chlorite, epidote and finally to carbonates and limonite.

Augite—The augite of the andesites may occur either as a porphyritic constituent or as a constituent of the ground-mass. In the former case it usually shows more or less perfect form. It is frequently found in association with a rhombic pyroxene in which case its crystalline outlines are generally much less perfect than those of the latter mineral. The augite, unlike the hornblende, rarely if ever gives any evidence of having been corroded by the magma. The development of augite at the expense of hornblende has already been referred to. The augite of the diorites is generally pale in colour (malacolite). It is frequently twinned and in some cases shows the diallagic striation.

Rhombic pyroxene.—This is one of the most important constituents of the intermediate group of rocks. It is a ferro-magnesian bisilicate which plays the same rôle in the intermediate rocks that olivine (a ferro-magnesian monosilicate) does in the basic rocks. In the andesites it occurs in the form of well-developed crystals. The general characters of the minerals belonging to this group have already been referred to and need not therefore be repeated (see *ante*, pp. 87 and 163).

In the diorites (*e.g.* enstatite-diorites of Penmaenmawr) the crystalline form is somewhat less pronounced than in the andesites; the angles being generally somewhat rounded. By ordinary alteration the rhombic pyroxenes pass into green fibrous aggregates. The intensity of the pleochroism varies considerably. The nearly colourless varieties may be regarded as enstatite proper and the strongly pleochroic varieties as hypersthene. It must be remembered, however, that the term enstatite is often used to cover the entire group of rhombic pyroxenes.

Mica.—The dominant mica is a brown biotite with small axial angle. In the andesites it almost invariably occurs in well-formed hexagonal tables. These have sometimes been acted upon by the magma exactly in the same way as the hornblende; and kernels of unaltered biotite are then seen to be surrounded by a black border of magnetite, with or without augite microlites.

The biotite of the diorites also occurs in hexagonal tables; the crystalline form is, however, frequently less perfect than in the andesites. Sometimes it occurs in ophitic plates penetrated by lath-shaped felspars

and containing inclusions of felspar. The pleochroism in sections at right angles to the principal cleavage is generally very strong. The colour changes from a pale yellow or yellowish brown for rays vibrating at right angles to the principal cleavage (parallel to a) to a very dark brown and in some cases almost black for rays vibrating parallel to the principal cleavage. There is, in the nearly uniaxial biotites, no appreciable difference for rays vibrating parallel to the β and γ axes, both of which lie approximately in the plane of easy cleavage. The biotite very frequently contains inclusions of apatite and magnetite. By alteration it passes into chlorite and this alteration often proceeds along the cleavage planes so that lamellæ of chlorite alternate with lamellæ of unaltered biotite. Minute granules and prisms of epidote are often associated with the chlorite. The ultimate alteration products are carbonates and limonite.

Iron-ores.—These occur sparingly in rocks of intermediate composition. In the andesites they are present as grains and crystals in the ground-mass and as inclusions in the porphyritic constituents. We have already explained that they are in part of secondary origin, arising from the action of the magma on crystals of hornblende and biotite. In the diorites they are also present in grains and crystals (often octahedra of magnetite), usually larger than in the andesites. As a rule the crystals appear to be magnetite and not ilmenite. The titanic acid of the diorites appears to occur in sphene rather than in iron-ores. In some cases it occurs in the form of rutile. Thus CROSS[1] observed rutile-inclusions in the green biotite of a quartz-diorite from St. Brieux in Brittany. It is possible, of course, that in this case the rutile is a secondary mineral arising in consequence of the separation of titanic acid from the biotite. The colour of the biotite, as ROSENBUSCH points out, is suggestive of alteration.

Sphene.—This mineral is extremely common in the diorites, especially in the hornblende-diorites. It occurs in well-formed crystals and as irregular grains. The crystals are generally yellowish or reddish; the minute grains are often colourless and similar to those derived from the alteration of titaniferous iron-ore. One very characteristic section is the acute rhombic. Twinning is not uncommon and the trace of the face of composition bisects the acute angles in the rhombic sections. The mineral possesses very high refractive and double refractive power, and these are the most useful characters in recognizing the mineral in the absence of form. The refractive power is so high that the mineral always appears bounded by broad dark borders. Another feature of considerable use is the strong dispersion of the optic axes ($\rho > \nu$). This may be determined in the minute grains which arise in consequence of the alteration of titaniferous iron-ores.

Apatite.—This mineral is almost constantly present but it presents no features worthy of special note. *Zircon* occurs occasionally as an accessory constituent.

(1) T.M.M., 1880, III., p. 369.

Description of the Rocks.

We recognize two principal divisions in the present group—the diorites and the andesites. In chemical composition these two groups resemble each other. The essential difference between them is one of texture. The typical diorites are holo-crystalline and granitic; the typical andesites are semi-crystalline and trachytic.

The textural differences correspond very closely with differences in mode of occurrence. The diorites usually occur as intrusive masses; the andesites, as lava flows. This difference in mode of occurrence is, however, not always observed; the margins of intrusive masses often assume an andesitic character and the centres of massive lava flows a dioritic character. It is, therefore, impossible to frame any rigid definitions of the two groups. We will consider first of all the rocks of the dioritic and afterwards those of the andesitic group. If we fix our attention on mineralogical composition we observe that the diorites may be subdivided according to the nature of the dominant ferro-magnesian constituents—augite, enstatite (hypersthene), hornblende and biotite. Two or more of these constituents are frequently present. Hence, in addition to the augite-diorites, enstatite-diorites, hornblende-diorites and mica-diorites we have such varieties as enstatite-augite-diorites and hornblende-mica-diorites.

Prof. Zirkel[1] describes a quartz-diorite from Arran. It is associated with Lower Carboniferous Sandstone and occurs on the left-hand side of the road to Shedog as it crosses the watershed separating Glen Shirrag from Glen Laodh. The rock is described by Zirkel as a fine-grained mixture of white felspar and greenish black hornblende with some quartz, which, however, can only be recognized by the use of the microscope. Plagioclase dominates over orthoclase; green epidote surrounds the hornblende in places, the quartz contains fluid inclusions; magnetite and apatite are present. The rock is holo-crystalline.

A slide prepared from a specimen of this rock given to the author by Mr. Miers contains in addition to the above-mentioned constituents both augite and biotite. The hornblende is green. It is both idiomorphic and allotriomorphic. The idiomorphic hornblende shows in cross-sections not only the clinopinacoid and prism faces but also the orthopinacoid. The allotriomorphic hornblende occurs in ophitic plates penetrated by the lath-shaped felspar sections. Both varieties are found in one and the same slide. The felspar occurs in lath-shaped sections and does not as a rule show multiple twinning. Quartz fills up the angular spaces between the felspar sections. The augite occurs in colourless crystals or grains. It shows characteristic cleavages and optical characters (maximum extinction observed 35°). The biotite occurs sparingly. It is very

(1) Z.D.G.G., 1871, p. 30.

strongly dichroic. This variety of the rock is therefore a hornblende-augite-biotite-diorite.

Prof. ZIRKEL mentions the fact that the rock contains rounded concretionary masses, somewhat finer in grain and richer in hornblende than the main mass. The occurrence of such concretionary (?) masses is a common feature both in the diorites and the granites.

Dioritic rocks occur as intrusive sheets in the limestones and quartzites of the Assynt district. The hornblendes of these rocks are remarkable for their zonal structure and for the perfection of their forms. They appear to be always idiomorphic with respect to the felspar. Crystals of hornblende detached from the rock show the forms (110), (010), ($\bar{1}11$) and (001). In thin sections the form (100) may also be occasionally observed. The pleochroism is well marked:—a, pale green to yellowish green; β and γ, deep green with only slight differences. Twinning is very common. Sometimes a crystal may be seen to be composed of three or four lamellæ. The alteration of the hornblende is accompanied by the formation of chlorite, epidote and opacite. In the diorites proper, as distinguished from the hornblende-porphyrites, the felspar occurs in irregular grains and appears to belong only to one period of consolidation. The felspar-aggregate plays the rôle of ground-mass, and the well-formed hornblende crystals lie in it without any regard to the orientation of the individuals of which it is composed. The coarseness of the felspar-aggregate varies within wide limits, sometimes it is so fine as to merit the term micro-crystalline; at other times it is so coarse as to remind one of the structure of a medium-grained granite. Pyroxene is not constantly present in these rocks. It is pale green when examined on a fractured surface of the rock, but colourless in thin section. It occurs in somewhat imperfect crystals and also as grains and granular aggregates. The forms of the crystals, so far as they are developed, appear to be those of the common rock-forming augites. The maximum extinction in the prismatic zone is about 40°. The only cleavages recognized are those of the prism. The mineral has been especially noticed in rocks which are intrusive in the dolomitic limestone; but it varies very much in quantity even in these, sometimes being absent altogether, and at other times occurring almost as abundantly as the hornblende. The other minerals are magnetite, apatite, calcite, epidote and quartz. The quartz appears to be in general a secondary product. The calcite is present in large crystalline plates which, in some cases, fill up the interspaces between comparatively unaltered felspar.

The above minerals occur in very different proportions in the different classes of hornblende-bearing rocks from the neighbourhood of Inchnadampf. In some the hornblende is very abundant. These have as a rule a granular texture and may be termed diorites. They tend to become porphyritic in places by the conspicuous development of hornblende crystals. The following analyses represent the composition of two varieties of diorite. The first is free from pyroxene or contains it only in very small quantity: the second is rich in pyroxene. A comparison of the two

analyses points to the conclusion that the pyroxene is a lime-magnesia-bisilicate (diopside).

		I.		II.
SiO_2	... ...	54·09	... ...	52·47
Al_2O_3	... ...	15·02	... ...	12·15
Fe_2O_3	... ...	4·12	... ...	3·47
FeO	... ...	5·15	.. ...	5·23
CaO	... ...	7·72	... ...	9·71
MgO	... ...	7·28	... ...	9·94
Na_2O	... ...	1·99	... ...	2·81
K_2O	... ...	3·55	... ...	2·26
H_2O) CO_2)	.. ...	1·49	... ...	1·62 ·54
		100·41		100·20

I. Diorite containing little or no pyroxene; base of Ben an Fhurian. (TEALL.)
II. Hornblende-augite-diorite, intrusive in dolomitic limestone, near Inchnadampf. (TEALL.)

In addition to the rocks of a more or less decided granitic texture we find others, in the same neighbourhood, of a markedly trachytic character. These will be referred to when we speak of the andesites. They are distinguished from the diorites by their markedly porphyritic character and by the occurrence of two distinct generations of felspar.

One very interesting feature which a comparison of the different varieties of diorite brings out is the variation in the state of crystallization in the felspathic matrix. In certain compact rocks the individual felspars are minute and give more or less lath-shaped sections. It is impossible to determine the precise character of the original ground-mass in consequence of alteration, but it evidently approximated to that of the andesites. In the medium-grained rocks the micro-structure of the felspathic matrix is thoroughly granitic. Where the felspathic matrix is very fine in texture the rock assumes a porphyritic character, when only one generation of felspars is present, in consequence of the hornblende crystals being larger than the individuals of the matrix; where the felspathic matrix is coarse the porphyritic character is not noticeable. In both cases the hornblende is idiomorphic. As there has been no recurrence of phase in the process of consolidation the rocks with a fine-grained felspathic matrix would not be *porphyritic* in the sense in which that term is used by ROSENBUSCH.

A large mass of diorite is exposed in Glen Tilt, in Perthshire. The author possesses two specimens from this mass; one resembles a grey granite in aspect except that the hornblende crystals are fairly conspicuous; the other is a dark rock evidently containing more hornblende than the former, moreover the large cleavage surfaces of the hornblende show lustre mottling.

The grey diorite is composed of hornblende, felspar, biotite, quartz, apatite, sphene and iron-ores. The hornblende occurs in crystals and grains. It appears to be for the most part idiomorphic with respect to the felspar. The colour of the hornblende is variable, either some shade of brown or green. The felspar is idiomorphic with respect to the quartz. Twinning on the albite, pericline and Carlsbad types may be recognized. Much of

the felspar is perfectly fresh; here and there, however, a granular alteration product has been developed. This is sometimes scattered irregularly through the felspar substance and sometimes limited to the twin-planes. The biotite occurs sparingly and is generally intergrown with, or included in the hornblende. Sections at right angles to the cleavage change from a pale yellowish brown to a rich green as the stage is rotated. The original mineral has evidently been more or less altered. That the green mineral is not typical chlorite is proved by the fact that it possesses tolerably high double-refractive power. The quartz occurs in irregular grains. It plays the rôle of ground-mass as in the Arran rock already described and as in the augite-diorites (quartz-gabbros) of Carrock Fell. Apatite occurs in stout prisms. Sphene occurs as irregular reddish brown grains and also in the form of narrow zones surrounding the opaque iron-ores. It is distinguished by its high refractive and double-refractive power. The relation of the sphene to the iron-ore is not such as to imply that the former mineral has been produced at the expense of the latter. The sphene appears to have been developed on a nucleus of iron-ore.

The dark-coloured rock is composed of brown and green hornblende more or less turbid felspar, green biotite, quartz, iron-ores, apatite and epidote. The hornblende is often of a deep brown colour, similar to that of the hornblende of the picrites and olivine-diorites. It is often penetrated by lath-shaped felspar sections. Quartz and felspar are much less abundant than in the previous specimen. Sphene is not recognizable in the section examined.

Professor VON LASAULX [1] has described quartz-diorites and quartz-mica-diorites from the lower Palæozoic district of Co. Wicklow. A rock from Bennlettery (quartz-diorite) is described as consisting of plagioclase often much altered, hornblende, quartz, epidote, viridite, apatite and opaque iron-ores often bordered with titanomorphite [sphene]. A rock from Dunganstown, east of Rathdrum, is described as a mica-diorite. It consists of plagioclase, hornblende, viridite, mica, quartz, magnetite, calcite, pyrite, epidote and ferric oxide. The plagioclase is much altered and shows only aggregate polarization. The hornblende is largely replaced by viridite. Epidote occurs in yellowish pleochroic grains associated with the viridite. Mica is the most abundant constituent next to plagioclase. Basal sections are reddish brown in colour in the centre and green at the margins. Sections at right angles to the principal cleavage show intense pleochroism, changing from light yellow to dark brown as the stage is rotated over the polarizer. Basal sections examined in convergent light show the interference figure of a biaxial mineral with very small optic axial angle. Magnetite is scattered through the rock in the form of octahedra.

Specimens of some of these Irish diorites are present in the ALLPORT collection in the British Museum. A slide of the quartz-mica-diorite from Dunganstown agrees substantially with the description of VON LASAULX. The hornblende is variable in tint as in the Glen Tilt rocks. The

(1) T.M.M., Neue Folge, Vol. I., p. 443.

individuals are frequently twinned. They are partly idiomorphic and partly ophitic. The biotite like the hornblende varies in colour from brown to green. Sections at right angles to the principal cleavage often show alternating lamellæ of the brown and green varieties. The felspar is idiomorphic with respect to the quartz. Lath-shaped plagioclase is often seen lying in a matrix of quartz. Apatite is present as usual. A similar rock but with less quartz occurs at Kilmacreagh in the same county.

A rock which must be referred to the quartz-diorites is extensively developed in the ridge, coloured syenite and greenstone, which runs east and west about three miles S. of Haverfordwest in Pembrokeshire. It is well exposed in a quarry near Targate. It is distinctly crystalline and dark grey in colour. A similar rock occurs at Talbenny. An interesting feature connected with this rock is that it is intimately associated with a light coloured granite which is frequently seen cutting it in the form of veins. Both granite and quartz-diorite are cut by highly decomposed dykes of basic trap (diabase). The principal constituents of the diorite are hornblende, felspar, quartz, iron-ores and epidote. The hornblende is green in colour and occurs in the form of irregular grains. The felspar is generally much altered. Twin-striation may be frequently seen but it is not common even in the least altered rocks. Like the hornblende it occurs for the most part in irregular grains. In the most altered specimens grains of epidote are common in the felspars. Quartz is tolerably abundant, also in the form of irregular grains. Iron ores occur sparingly. The texture of the rock is granitic and no mineral appears to have obtained any very decided advantage over any other so far as the development of crystalline form is concerned. Here and there the felspar may be seen to be idiomorphic with respect to the hornblende. In some places the quartz-diorite may be seen to assume a gneissic structure in the neighbourhood of dislocation planes.

Very typical diorites occur in the Channel Islands, Guernsey and Jersey. Those from the former island have been described by Messrs. Hill and Bonney[1]; those from the latter by M. Noury.[2] A specimen from St. Clements, Jersey, is a medium-grained greyish rock of granitic texture, very similar in character to the more felspathic varieties of the Glen Tilt diorite. It is composed of felspar, mostly showing twin-striation, hornblende, biotite, quartz, iron-ores and apatite. The hornblende often shows traces of crystalline outline but it is frequently penetrated by lath-shaped felspars. The felspar is idiomorphic with respect to the quartz. The broad lath-shaped felspar sections are sometimes seen to be sharply terminated by crystalline faces where they penetrate into a large irregular individual of quartz. The hornblende varies in colour from brown to green. Biotite occurs sparingly. It is often changed to chlorite, in which epidote grains are scattered. Iron-ores and apatite occur sparingly.

Great difficulty is experienced in deciding on the boundary line between the quartz-mica-diorites and the hornblende-biotite-granites or hornblende-

(1) Q.J.G.S., Vol. XL. (1884), p. 404.

(2) Géologie de Jersey. Paris, 1886.

granitites. As an illustration of this difficulty we may refer to the so-called granite of Ballachulish. This is a medium-grained granitic rock composed of black mica, hornblende, felspar, mostly showing twin lamellation, quartz, sphene, apatite, zircon and epidote. The biotite occurs in hexagonal tables. Sections at right angles to the principal cleavage are characterized by the most intense dichroism. By alteration the mineral becomes green and is then frequently seen to be associated with epidote. The hornblende is green in colour and occurs sparingly. It is quite subordinate to the biotite. Felspar is colourless except where it has become turbid by alteration. As a rule it shows multiple twinning. The plagioclase is idiomorphic with respect to the quartz. The sphene occurs in irregular masses; it is pleochroic in reddish brown and yellowish brown tints. Notwithstanding the absence of form the mineral may be identified with certainty by its high refraction and double refraction, by its colour, and by the characteristic dispersion ($\rho > v$) seen in convergent light in sections approximately at right angles to an optic axis. Felspar is often seen to penetrate the sphene in such a way as to show that it belongs to an earlier phase of consolidation. It is possible, of course, that the sphene may be a pseudomorph after titaniferous iron-ore, but there is nothing to suggest this except the absence of form and its relation to the felspar. Original sphene is regarded by ROSENBUSCH as belonging in all cases to the earliest period of crystal building. Apatite occurs abundantly in long thin prisms. It is especially common in the biotite. Zircon occurs as minute irregular grains and as short stumpy prisms with well-marked terminations. The grains may be recognized by their strong refraction and double refraction; the crystals by these characters, by their form and by the fact that their double refraction, as determined by a quartz or selenite wedge, is positive.[1]

(1) Dr. SORBY has called attention (Microscopical Journal, 1877) to the use of the quartz-wedge in distinguishing between the two directions of extinction of any double-refracting crystal not cut at right angles to an optic axis. He calls these two directions the positive and negative axes—a mode of speaking of them to which exception may be taken, as the terms positive and negative are used with reference to the character of the bisectrices (the first and second mean lines) in a biaxial crystal, and also with reference to the character of the double-refraction of any crystal not belonging to the cubic system. The two directions in question may be conveniently referred to as the major and minor axes of depolarization. If the section happens to be cut parallel to two of the axes of the ellipsoid then the major and minor axes of depolarization will of course correspond with the two axes of the ellipsoid. If the section be cut parallel to one of the axes of the ellipsoid then either the major or minor axis of depolarization as the case may be, will correspond with this axis. If the section be not cut parallel to any one of the axes of the ellipsoid we may still speak of the major and minor axes of depolarization. Adopting this nomenclature we see that Dr. SORBY's positive axis is our minor axis, and his negative axis is our major axis.

Now to determine which is the major and which is the minor axis in any given section we require a quartz or selenite wedge cut so as to show NEWTON's scale of colours from the neutral tints of the first order to the colours of the fifth and sixth orders at least. The directions of the major and minor axes of the ellipse must be determined in the wedge. In a quartz-wedge cut in the usual way—that is with the length of the wedge parallel to the vertical axis of the prism—the minor axis lies parallel to the length of the wedge. Let us take such a wedge.

To make an observation we place the crystal section in the position of extinction and then move it through 45°; by this means we put it with certainty into the position of maximum

The extinction is of course parallel to the length of the prism. Apatite occurs in long colourless prisms, as inclusions in all the other minerals. It is especially conspicuous in the biotite.

Rocks of a dioritic character are extensively developed in the northern portion of the Malvern range. They consist of felspar, green hornblende, biotite, titaniferous iron-ore, sphene, quartz, apatite, chlorite and epidote. The felspars are generally more or less turbid. Under crossed nicols the turbidity is often seen to be due to minute scales of a vividly polarizing mineral. In some cases the felspars have been replaced by interlacing aggregates of white mica and a colourless granular mineral of high refractive and double-refractive power (epidote?) Yellowish pleochroic epidote is usually present and sometimes one and the same individual may be seen to be coloured in one part and colourless in another. The pleochroism of the common hornblende is as follows—a, brownish yellow; β and γ, rich deep green. The hornblende often passes into chlorite with which epidote-granules, opacite and ferrite are associated. The sphene rarely shows good form. In some slides the grains or imperfect crystals of sphene contain nuclei of iron-ore, the relations of the two minerals being similar to those described by VELAIN [1] as occurring in a hornblende-gneiss from Siberia. Quartz is present in variable quantity in the form of grains. Apatite is sometimes very abundant in tolerably thick prisms. Strongly pleochroic biotite is sometimes present, sometimes absent. Epidote not only occurs in the rock, as already mentioned, but also in the form of veins

The rocks are often gneissose in structure and they exhibit a considerable amount of variability so far as the relative proportions of the constituents are concerned. Some are thoroughly basic in character owing to the predominance of the ferro-magnesian constituents, others form a kind of transition between the intermediate plutonic and the acid plutonic

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effect—that is with its major and minor axes of depolarization at angles of 45° to the planes of polarization of the polarizer and analyser. We then slide in the quartz-wedge between the analyser and the eye-piece, taking care to keep its length inclined at 45° to the cross-wires. If we slide it in one way we observe that the effect is to raise the tints of the section in NEWTON's scale, and if we slide it in the other way (at right angles to the former) we observe that the effect is to depress the tints. In the latter case it will not be difficult to find a position in which compensation takes place and the section appears dark. Now in this position the major axis in the wedge lies parallel to the minor axis in the section and vice versâ; the directions of the axes in the wedge being known, those in the section may be at once determined.

If we make this observation on any uniaxial mineral lying with its optic axis parallel or approximately parallel to the stage of the microscope we can at once state whether the double-refraction of the mineral is positive or negative. If the minor axis in the crystal lies parallel with the optic axis (as in quartz) the double-refraction is positive; if the major axis lies parallel with the optic axis (as in apatite) the double-refraction is negative. Assuming the strongly refracting and strongly double-refracting mineral mentioned above to be uniaxial, we can state definitely that its double refraction is positive and this agrees with zircon.

The character of the double-refraction in biaxial minerals cannot be determined in this way unless we know that the section in question contains the acute bisectrix and unless we also know in which direction the acute bisectrix lies. Thus we cannot distinguish enstatite from hypersthene by this method, although we can easily prove that in longitudinal sections of the rhombic pyroxenes the minor axis of depolarization always coincides with the length of the section—that is with the vertical axis of the crystal. In other words we can prove that $c=\gamma$.

(1) B.S.G., 3rd Se., Tome XIV. (1885). p. 142.

groups. The relations of the individual constituents are those of granitic rocks. None of the principal constituents shows good form. In some of the specimens we find distinct indications of cataclastic structures. Bands of liquid cavities sometimes traverse the quartz grains without any regard to the orientation of the different individuals. The twinned felspars appear faulted and bent and planes of movement, now occupied by a mosaic of quartz and felspar, may be followed for greater or less distances across certain slides.

The so-called syenites of Charnwood Forest may with propriety be considered in the present connection. They are of intermediate composition and plagioclase is certainly as abundant, if not more abundant, than orthoclase. They have been described by Messrs. HILL and BONNEY.[1] In the southern portion of the Charnwood Forest district the rocks are well exposed in large quarries at Groby, Markfield and Cliff Hill. They are found also in Bradgate Park and Hammer Cliff. Closely allied rocks occur in the northern portion of the district, at Bawdon Castle, Long Cliff and New Cliff near Garendon.

The rocks occurring at Groby, Markfield and Cliff Hill are very similar in character. The dominant variety is coarsely crystalline. A fractured surface is mottled with pale green, pink and black patches. Microscopic examination shows that the pale green patches represent plagioclase, often zonal in habit and more or less idiomorphic; that the black patches represent the ferro-magnesian constituents hereafter to be described; and that the pink patches are not individual minerals but a micropegmatitic intergrowth of felspar and quartz which plays the rôle of ground-mass. The pegmatitic character of the pink patches may sometimes be recognized on a cut surface of the rock or even on the cleavage surfaces exposed on a clean fracture. The lustre of the cleavage of the felspar is interrupted by the quartz with which it is intergrown. As a general rule the felspar of the pink patches does not show multiple twinning. It may with considerable confidence be regarded as orthoclase, whereas the green idiomorphic felspar is probably oligoclase, as in the somewhat allied rock from Quenast[2] in Belgium. The original ferro-magnesian constituents were augite, hornblende and biotite. Unaltered augite is present in most of the slides examined by the author. It is colourless and closely resembles the augite of the augite-granites. In some slides it shows crystalline outlines but these are never very well defined. Diallagic striation parallel to the basal plane is not uncommon and sometimes crystals showing this striation are repeatedly twinned in the ordinary way. Clino-pinacoidal sections of such crystals give the high extinction of augite and show the characteristic herring-bone lineation. The colourless augite is often associated with green fibrous uralite or chlorite. The original hornblende, so far as the observations of the writer enable him to judge, was less abundant

(1) Q.J.G.S., Vol. XXXIV. (1878), p. 199.

(2) VALLÉE-POUSSEN ET RENARD. Mémoire sur les charactères minéralogiques et stratigraphiques des roches dites plutoniennes de la Belgique et de l'Ardenne Française, publ. par l'Acad. Roy. Bruxelles, Tome XL.

than the augite. It was brown in colour and occasionally possessed definite form so far as the prismatic zone is concerned. It is now largely represented by chloritic alteration products with which epidote is associated. The biotite is now green. Sections at right angles to the principal cleavage exhibit a marked dichroism: a, pale yellowish brown, β and γ green. Sometimes the biotite is represented by feebly polarizing chlorite; as a rule the double refraction is stronger than it is in typical chlorite. Ilmenite more or less changed to leucoxene and often exhibiting the reticulated structure so common in the diabases is present in almost all slides. Apatite occurs in long slender prisms. The idiomorphic felspar in this rock has generally been rendered more or less turbid by the development of vividly polarizing granular matter. Green secondary products resulting from the decomposition of the bisilicates have sometimes migrated, so to speak, into the felspars. The felspathic constituent of the micro-pegmatite is often as fresh and unaltered as the quartz with which it is intergrown.

From the above description it appears that the original rock consisted of plagioclase, augite, hornblende, iron-ores and a matrix of micro-pegmatite. Alteration has given rise to uralite, chlorite, leucoxene and epidote. The last-mentioned constituent occurs abundantly in all the slides and may be often recognized macroscopically in nests and veins. Pyrite also occurs pretty frequently. So far reference has been made to the coarse-grained variety. Associated with this is a rock of finer grain. This is redder in colour and appears to contain a smaller proportion of the ferro-magnesian constituents. Messrs. HILL and BONNEY state that crystals of plagioclase appear to be more abundant in this than in the other variety.

The rocks from the northern portion of the district are shown by the authors just mentioned to be closely related to those above described. Somewhat similar rocks occur in the neighbourhood of Narborough, some six or seven miles south of Groby. These may be regarded as inliers of the Charnwood rocks. The rock of Enderby is interesting as illustrating a kind of transition between the granitic and the trachytic textures. It consists of more or less decomposed plagioclase crystals, corroded quartz-grains, green decomposition products after the ferro-magnesian constituents, magnetite or ilmenite and a micro-crystalline mosaic of quartz and turbid felspar which constitutes the ground-mass. The porphyritic felspar appears to be wholly plagioclase. The porphyritic quartz has the aspect of the quartz in the liparites and quartz-felsites. The rock differs from the dacites merely in the fact that the ground-mass is micro-granitic. In composition it is evidently more acid than the normal rocks of Groby and Markfield.

Some analyses of Charnwood rocks have been made by Mr. BERRY.[1] The silica percentage of the Markfield rock is given as 56·78; that of the Garendon rock as 51·54; and that of the rock from Huncote quarry, Croft Hill, as 64·30.

The augite-bearing rocks of Markfield, Groby and Bradgate possess

(1) Q.J.G.S. Vol. XXXVIII. (1882), p. 197.

affinities with the rocks described as quartz-gabbros (augite-diorites) from Carrock Fell already referred to and with some of the augite-granites to the Cheviot District, which we now proceed to describe.

The Cheviot District is characterized by the extensive development of lavas and tuffs of intermediate composition—andesites and porphyrites. In the central portion of the district, about Hedgehope and Staindrop, we find granitic rocks which doubtless belong to the same phase of igneous activity as the lavas and tuffs. These granitic rocks vary considerably in the relative proportions of the different constituents; some are dark in colour owing to the abundance of ferro-magnesian constituents, others are grey or pink and similar in general aspect to many normal granites. The dark-coloured rocks closely resemble in general appearance the so-called syenite of Markfield and Groby. They may be studied in the neighbourhood of Linhope Spout. Microscopic examination merely serves to confirm the impressions derived from an examination of the hand specimens. The rocks consist of idiomorphic plagioclase, augite, biotite, magnetite or ilmenite and a micro-pegmatitic (granophyric) matrix. The difference between these rocks and those of Charnwood lies in the absence of original hornblende and the better preservation of the augite and biotite. Epidote, so abundantly developed in the Charnwood rocks, has not been observed in the corresponding rocks from the Cheviot district.

The augite of these rocks is present in the form of irregular grains, granular aggregates and sometimes, though rarely, in more or less definite crystals. It is almost colourless in thin section. Inclusions of magnetite are not uncommon. Transverse sections show the characteristic cleavages, and longitudinal sections give a maximum extinction of 43 or 44 Twinning may occasionally be observed. Dr. ALPHONSE MERIAN (N. J. Beilage, Band. III., p. 262) has isolated and analysed the augite of an allied rock from Laveline in the Vosges. It possessed the following composition :—

SiO_2	...	50·63
Al_2O_3	...	·87
Fe_2O_3	...	3·33
FeO	...	8·39
MgO.	...	13·01
CaO	...	21·30
Na_2O	...	1·02
K_2O	...	·50
TiO	...	·79
		99·84
Sp. Gr.	...	3·372

It is therefore a non-aluminous iron-bearing augite of the diopside type (malacolite, *Rosenbusch*).

The lighter coloured and more typical granites from Staindrop, Combe Fell and Hedgehope are closely related to the rocks just described. They will be referred to in the chapter on granites.

The interesting group of the enstatite-diorites is represented in this country by the rock so extensively quarried in the neighbourhood of Penmaenmawr, Caernarvonshire. This rock has been described by

Mr. J. A. PHILLIPS.[1] It must be remembered, however, that at the time when his description was written the modern methods of recognizing the rhombic pyroxenes were not generally known and he therefore described the pleochroic enstatite as hornblende. Rocks similar to those of the Penmaenmawr quarries occur at Klausen in the Tyrol. They have been investigated by TELLER and VON JOHN who have described them as norites and quartz-norites. It seems desirable to limit the term norite to basic rocks and we accordingly prefer to call the Penmaenmawr rock an enstatite-diorite. In the first edition of his work on the massive rocks ROSENBUSCH referred to the Penmaenmawr rock as an enstatite-diabase and in a paper on the Whin Sill the present writer described it as a bronzite-diabase. Mr. PHILLIPS called the rock a quartziferous diorite.

The least altered varieties consist essentially of felspar, enstatite, augite, biotite, iron-ores and quartz. The dominant felspar is undoubtedly plagioclase. Twinning on the albite plan is common and this is sometimes associated with twinning on the Carlsbad plan. The common form of the sections is lath-shaped. In the larger individuals the extinction is usually not simultaneous for the whole of the section. The marginal portions extinguish at lower angles than the central portions. Differences of 10° or 12° are not uncommon. The two portions are not separated from each other by sharp lines. The optical properties vary in the most gradual manner from the centre towards the margin. These facts probably indicate that the larger felspars vary in composition, the central parts being more nearly allied to anorthite than the marginal parts of the same individual. In some slides the plagioclase occurs in the form of tolerably large individuals and also as small columnar crystals giving lath-shaped sections. Mr. WALLER[2] observed six extinctions lying between 54° and 56° and accordingly inferred the existence of labradorite. Messrs. TELLER and VON JOHN isolated and analysed the plagioclase of an allied rock from Klausen in the Tyrol. Their analyses prove that in this case the felspar lies between andesine and labradorite.

In the Penmaenmawr rock the plagioclase is seen to be idiomorphic with respect to the quartz as in so many other rocks of the diorite family. The quartz indeed plays the rôle of ground-mass. It often occurs in ophitic masses which possess uniform optic properties over considerable areas in a microscopic slide. This interstitial quartz is, however, frequently intergrown with an untwinned felspar which may with considerable confidence be regarded as orthoclase. The micro-pegmatite so formed is sometimes perfectly colourless. The felspar is then as clear and limpid as the quartz. In such cases the only means of distinguishing one mineral from the other in parallel polarized light depends upon the difference in double-refractive power. This difference, though very slight, is often decisive. To apply the test the sections should be of such thickness that the quartz sections cut parallel to the optic axis polarize in the pale yellow tints of the first order. This is the case with the slides as they are usually

(1) Q.J.G.S. Vol. XXXIII. (1877), p. 423.

(2) Midland Naturalist, 1885, p. 4.

prepared. In such sections orthoclase never shows any colour under crossed nicols. It polarizes always in neutral tints. Where micropegmatite occurs in the rock it always plays the rôle of ground-mass. The mother-liquor, left after the separation of the plagioclase, the ferro-magnesian constituents and the iron-ores, crystallized as micropegmatite exactly as in the rocks of Groby and Markfield.

Of the ferro-magnesian constituents enstatite (ferriferous) is by far the most important. It is usually represented by green fibrous pseudomorphs (biotite) but in some of the least altered rocks it still preserves its original character. It is then seen to possess the pleochroism of hypersthene. Longitudinal sections are brown or reddish-brown for rays vibrating at right angles to the principal axis and green for rays vibrating parallel to this axis. Crystalline forms may be observed but the angles are as a rule somewhat rounded. The forms in the prismatic zone are (100), (110) and (010) as in the enstatite-andesites and the pinacoidal forms are developed at the expense of those of the prism. The terminal faces, so far as they can be determined, appear to be the flat domes characteristic of the rhombic pyroxenes. Longitudinal sections of the altered crystals are pleochroic in shades of green—the greatest absorption occurring when the rays vibrate parallel with the vertical axis. It is worthy of note that the double-refraction of the green crystals is higher than is common in the rhombic pyroxenes.

Augite, which is almost always present, is allotriomorphic. It is very pale brown and devoid of pleochroism. Twinning according to the ordinary law is very common and the sections not unfrequently show the diallagic striation parallel to the basal plane. In clino-pinacoidal sections of twinned individuals this striation gives rise to what may be termed the herring-bone structure. The augite is often fresh when the enstatite has been entirely replaced by the green fibrous mineral. Biotite occurs very sparingly in the form of ragged plates (ophitic) often penetrated by the lath-shaped felspars. In its fresh condition it is very strongly dichroic; the colour for rays vibrating parallel to the principal cleavage being a rich deep brown It passes into green chloritic alteration products. Iron-ores are present. Sometimes they occur in ragged plates or skeletons, suggestive of ilmenite. Apatite is present in long slender prisms and is sometimes very abundant in local patches. The quartz often contains liquid cavities with moving bubbles. In the more altered rocks the felspars are replaced by greyish granular matter giving aggregate polarization.

The normal rock is of medium grain and of a greenish grey colour. Irregularly distributed through it are certain light grey veins and patches These have been specially investigated by Mr. WALLER. They differ in chemical and mineralogical composition from the main mass of the rock in a very striking and suggestive manner. They contain about 7 p. c. more silica and about 1·5 p. c. more alkali. Moreover the potash is in excess of soda in the veins, whereas the reverse relation holds in the rock itself. The ferro-magnesian constituents are less abundant in the veins than in the rock. Ilmenite, more or less changed to leucoxene, and

possessing the reticulated structure so common in the lower Palæozoic diabases, appears on the other hand to be somewhat more abundant. Chemical analysis shows that the iron is about equal in the rock and in the veins, but that the lime and magnesia are more abundant in the former than in the latter. The iron of the veins is mainly present in ores, not in ferro-magnesian silicates.

The veins exhibit the most perfect illustrations of micro-pegmatite that can possibly be imagined. The rock of which they are composed is in fact a granophyre. The felspar intergrown with the quartz is generally turbid so that no difficulty is experienced in separating the two minerals. The ferro-magnesian constituent of the veins is augite. Enstatite is rare if not entirely absent. Now on comparing the veins with the rock it will be noted at once that they consist of the minerals which formed last; in other words they consist of augite, orthoclase and quartz. Iron-ores separate at different times in the process of consolidation and may therefore be left out of account. These facts point strongly to the conclusion advocated by Mr. WALLER, that the veins are of the kind known as contemporaneous. They are composed of the mother liquor left after the separation of the more basic compounds. The occurrence of augite is conclusive as showing that the veins are igneous products and not exfiltration veins formed after the complete consolidation of the mass. In mineralogical composition these veins are related to the augite-granophyres of Carrock Fell, Barneveve Mountain (Carlingford district in Ireland) and Mull.

At the margins of the intrusive mass the rock of Penmaenmawr tends to become compact and porphyritic. Mr. WALLER states that a slice of the compact variety is almost entirely made up of interlacing felspar crystals with occasional porphyritic ones of larger size. He thinks that in the interstices there may be a small amount of residual glass. It is thus evident that the rock at its margins assumes a trachytic texture. The normal holo-crystalline rock is the plutonic equivalent of the enstatite-augite-andesites hereafter to be described. The following analyses by Mr. PHILLIPS represent the composition of different varieties of the normal rock. The analysis by Mr. WALLER represents the composition of one of the grey veins. An analysis of one of the Klausen rocks is inserted by way of comparison :—

	I.	II.	III.	IV.	V.
SiO_2 ...	58·45	62·24	61·75	65·1	59·97
Al_2O_3 ...	17·08	18·25	18·88	12·9	16·93
Fe_2O_3 ...	·76	1·05	·52	2·0	2·41
FeO ...	4·61	3·08	3·52	4·7	4·83
MnO ...	tr.	tr.	tr.	tr.	—
CaO ...	7·60	4·69	3·54	4·7	5·10
MgO ...	5·15	2·27	1·90	2·8	3·61
K_2O ...	1·02	1·49	1·24	3·9	1·32
Na_2O ...	4·25	3·79	3·67	2·8	3·87
P_2O_5 ...	tr.	tr.	tr.	—	—
FeS_2 ...	—	·39	·09	—	
H_2O ..	1·07	2·69	4·46	1·9	1·60
	99·99	99·44	99·57	100·8	99·64
Sp. Gr.	2·94	2·75	2·79	2·72	—

I. From the most westerly quarry. Rock comparatively unaltered. (PHILLIPS).
II. From the most easterly quarry. Rock considerably altered; felspars almost completely kaolinized. (PHILLIPS).
III. From Messrs. BUNDRIT & Co's eastern quarry. Rock more altered than the last. (PHILLIPS).
IV. Grey vein, from the same quarry as No. I. (WALLER).
V. "Quartz-norite" from the Vildarthal near Klausen. (TELLER and VON JOHN.)

Mr. PHILLIPS' specimens were selected to illustrate progressive metamorphism by surface agencies. The analyses prove that this metamorphism is accompanied by the removal of lime and magnesia and by the formation of hydrated silicates (the water in No. III. was found to be combined; not hygrometric). The two last analyses must be compared with the first analysis by Mr. PHILLIPS; not with the second and third which represent altered rocks.

Mr. WARD has described several rocks occurring in the northern part of the Lake District under the term diorite. The Little Knott rock has already been alluded to (see *ante*, p. 100). Quartz-diorites occur, according to Mr. WARD, at Seathwaite How, Hindscarth, and Burtress Comb. These rocks appear to be all very much altered and not very typical of their class. A specimen from Seathwaite How collected by the author is a fine-grained greyish rock mainly composed of turbid felspar with which is associated a little quartz possibly of secondary origin. The original ferro-magnesian constituents appear to have been a pale augite and biotite. They are more or less replaced by green decomposition products, possibly in part uralitic. Ragged plates and skeletons of iron-ore are scattered through the slide. The ferro-magnesian constituents are completely subordinate to the felspathic constituents and the rock appears to belong to the leucophyre division of the diabases rather than to the diorites.

Rocks of a dioritic character occur in the Lizard peninsula. They are present as veins in the gabbro at Pen Voose and they also constitute a part of the banded gneissic series which Prof. BONNEY proposed to call the granulitic series. This series consists principally of two types of rock—a diorite and a fine-grained granite. In some places the two types may be seen veining each other after the manner of igneous rocks; in others they occur in parallel bands, sometimes puckered, as is common in banded gneisses. Parallel structure (foliation) is often seen in the arrangement of the constituents when the rocks themselves exhibit a parallel structure on the large scale. To what extent the parallel structure is due to movements posterior to consolidation has not as yet been determined. The relation of the dioritic and granitic rocks to the gabbros and serpentines is also involved in some obscurity. They are in part at any rate of later date for they occur as veins in the gabbro and sometimes contain included fragments of that rock.

The constituents of the dioritic rocks are felspar, biotite, green hornblende, sphene, iron-ores and apatite. The felspar is sometimes turbid and sometimes fresh. The fresh felspar in the massive (non-foliated) rocks usually shows multiple twinning, but in the rocks possessing more or less

it is often almost destitute of twinning. In the present state of our knowledge it is not safe to regard the untwinned felspar as orthoclase. As a rule the felspar does not show crystalline form. It occurs as grains of tolerably equal dimensions in the different directions. In some of the rocks, however, distinct indications of porphyritic crystals, having more or less definite outline, occur. These are almost always more or less cloudy in consequence of the presence of vividly polarizing scaly (micaceous) or granular matter. In the foliated varieties they are more or less replaced by a felspar-mosaic. In short, the foliated diorites bear the same relation to the massive diorites, that the foliated gabbros do to the massive gabbros, and the foliated granites to the massive granites. Indeed it is extremely interesting to note how similar are the structural characters, both microscopic and macroscopic, of the foliated representatives of the different types of massive plutonic rocks. The biotite of these rocks is remarkable for its richness of colour (see Fig. 1, Plate XXXII.). It occurs in somewhat irregular plates. The pleochroism is as follows:—α pale yellowish brown, β and γ a rich reddish brown. It varies in amount in different specimens, sometimes being almost the only ferro-magnesian mineral present. The hornblende is the green variety. It occurs for the most part in irregular grains. In the more massive rocks which occur as veins in the gabbro and in which no interstitial movement has taken place either during or subsequent to consolidation it is sometimes seen to form ophitic plates containing inclusions and penetrations of felspar. In the foliated rocks this mode of occurrence has not been observed. Sphene is almost invariably present. It occurs as irregular grains and also as exquisitely-formed crystals. In some varieties the characteristic lozenge-shaped sections bounded by faces of the form $(\bar{1}23)$ are tolerably abundant. Notwithstanding the perfection of form in so many of the sections the mineral appears to have been developed, in part at any rate, after the felspar for it contains inclusions of the latter mineral. The irregular masses of sphene bear the same relation to the felspar as those of the diorite or granite of Ballachulish. Iron-ores are very sparingly represented in these rocks. They occur as irregular grains and are seen in some varieties to be surrounded by a narrow border of sphene.

The structural and mineralogical changes accompanying the plastic deformation of masses of diorite under the stresses involved in mountain making have not as yet been worked out in detail. It will doubtless be found that the diorites like the gabbros and granites pass over into gneissose and schistose rocks. Slides of the quartz-diorite (tonalite) of Mount Adamello illustrate certain phases of dynamic metamorphism in a very perfect manner. The plates of biotite may be seen to have been crumpled and puckered and the crystalline grains of quartz and felspar to have been strained, broken and even reduced to a micro- or crypto-crystalline aggregate. This aggregate winds in and out amongst the larger crystalline particles and sometimes forms a kind of matrix in which these lie embedded. In its relation to the other constituents it exhibits in great perfection what may be aptly termed micro-flaser structure.

We have now to consider the volcanic representatives of the intermediate group. We adopt the term andesite as the general name for this division. Where the rocks have been subjected to widespread and extensive alteration, as is especially the case with those of pre-Tertiary age, the term porphyrite will be frequently employed.

Typical andesites of Tertiary age are not known to occur in the British Isles. The rocks described in the previous chapter as andesitic dolerites and basalts might be called augite-andesites; but they are very different in character from the typical andesites of Hungary, the Andes and the Rocky Mountain region. M. BRÉON describes, under the term augite-andesite (andésite-augitique à labrador), certain rocks from Iceland which possess affinities with our andesitic dolerites. They are dark in colour and are composed essentially of microlites of felspar and augite with occasional porphyritic crystals of labradorite. These rocks succeed the olivine-dolerites. It is probable that the allied rocks which occur as dykes in the North of England, South of Scotland and Arran bear the same relation to the great sheets of olivine-dolerite occurring in the North of Ireland and West of Scotland.

Lavas and tuffs of intermediate composition are very common in certain Palæozoic areas. Those of the Cheviot district have been described to some extent by the present writer[1] and by Dr. PETERSEN.[2] The least altered rock is an enstatite-andesite, or to speak more correctly an enstatite-augite-andesite for both rhombic and monoclinic pyroxenes are present.

This rock was termed pitchstone-porphyrite by the earlier observers. It may be observed *in sitû* about a quarter of a mile above Windy Haugh; near Carl Croft on the Coquet; and near Fairhaugh on the Usway. It occurs abundantly as boulders in the Alwin. The best known exposure is in the north-eastern portion of the district near the village of Yetholm. The rock is black and possesses in its typical form a well-marked resinous lustre. It is porphyritic in texture; the porphyritic constituent being a fresh glassy looking triclinic felspar. Veins of opal and chalcedony, mostly stained red by ferric oxide, traverse the rock in various directions. The impregnation of trachytes and andesites with secondary silica in the form of opal has especially engaged the attention of Prof. VON LASAULX[3] and Dr. HATCH. A variety of the so-called liparite of Rosenau in the Sieben-gebirge containing 69·45 of SiO^2 has been shown by the former observer to be a normal sanidine-trachyte impregnated with secondary silica: 18·91 p. c. of the rock being soluble in a 40 p. c. solution of caustic potash. Dr. HATCH[4] has proved that some of the andesites of South America have been similarly

(1) G.M. Decade II. Vol. X. (1883), pp. 100, 145 and 252.

(2) Mikroskopische und chemische Untersuchungen am Enstatit-porphyrit aus den Cheviot Hills Inaug. Diss. Kiel, 1884.

(3) Sitzungsber. der niederrhein. Ges. Bonn 1885, p. 119.

(4) T.M.M. Neue Folge. Band VII., p. 332. The above solution was used by Dr. HATCH in the proportion of 20 c.m. to 1 gr. of the rock powder. The powder was treated over the water bath for one hour with repeated stirring. An increase in the length of the time of treatment did not appreciably increase the amount of matter dissolved.

impregnated with secondary silica so that the bulk analyses show abnormal silica percentages. When the veins in the Cheviot rock are wide the central portions are composed of colourless quartz or chalcedony, the marginal portions of a deep red substance. Dr. PETERSEN found that the specific gravity of the colourless portion was 2·440 and that of the red portion 2·071; the percentage of water in the former being 2·89 p. c. and in the latter 7·07.

The rock itself is composed of labradorite, ferriferous enstatite, augite, magnetite, hematite (eisenglimmer), felspar microlites and a glassy base. (Figs. 1 and 2, Plate XXXVI.). The labradorite crystals give a marked porphyritic character to the rock. They frequently measure from 2 to 3 mm. across. Under the microscope they are often seen to be completely honeycombed by ramifying inclusions of the ground-mass. Their outlines are frequently interrupted by inlets and creeks, also filled with the ground-mass. Twinning on the albite plan is very common and is sometimes associated with twinning on the pericline and Carlsbad plans.

The most abundant ferro-magnesian mineral is a ferriferous enstatite of the type characteristic of the pyroxene andesites. The forms in the prismatic zone are usually well defined. The terminal faces are frequently imperfect. The pleochroism is well defined in moderately thick sections. Monoclinic augite is invariably found in association with the rhombic pyroxene. The angles in the prismatic zone are not so sharp as in the latter mineral; indeed the mineral occurs rather as crystalline grains than definite crystals. The extinctions in the prismatic zone vary from 0 to 44°. The mineral is pale green in colour and devoid of pleochroism; so that in this rock the two pyroxenes may be readily distinguished by the simple test of pleochroism.

The ground-mass in which the above constituents lie embedded as porphyritic or micro-porphyritic elements varies in different specimens. One common type consists of small felspars, magnetite grains, hexagonal plates of hematite (eisenglimmer) and a colourless or slightly brownish glass often containing globulites and longulites. Another type may be described as a felted aggregate of felspar microlites lying in a glassy base (mikrolithenfilz). This type occurs in rocks which show the most perfect fluxion structure. The chemical composition of this rock and of the glassy base which it contains has been already given on page 43.

A somewhat exceptional rock to which the term augite-andesite may be applied occurs in the crags above Langlee Ford on the south side of the Harthope valley. Macroscopically it consists of porphyritic felspars measuring from 2 to 3 mm. across embedded in a very dark compact matrix. The specific gravity of the rock is 2·74 and the SiO_2 percentage is slightly over 60. Under the microscope the porphyritic constituents are seen to be plagioclase and augite. The felspar is frequently honeycombed with irregular inclusions of the ground-mass; but their most striking peculiarity is a cloudy appearance which can be shown, by means of a magnifying power of 1,000 diameters, to be due to minute inclusions similar to those frequently seen in the felspars of plutonic rocks. They exactly

resemble, for example, the inclusions in the felspar of the Baltimore gabbro described and figured by Mr. WILLIAMS.[1] Sections at right angles to the twinning planes are often seen under ordinary light to be finely striated in consequence of the arrangement of the inclusions in lines or rather planes parallel to the brachy-pinacoid. Under polarized light the same sections show the characteristic banding of plagioclase, and the maximum angle which has been observed between the extinction positions of adjacent lamellæ is 34° (maximum for oligoclase 37°). The pyroxene occurs in good-sized grains having the cleavages and extinction angles of augite and also as minute crystalline granules in the ground-mass. The larger grains rarely show any traces of crystalline form but they are frequently twinned. In the absence of colour and in general aspect they resemble the augite of the augite-diorites and augite-granites of the district. A pale brown mica occurs in minute scales. It is frequently aggregated in patches and when this is the case several scales overlap in the thickness of the preparation. This mica closely resembles that developed in the dolerites of Cornwall near their contact with granite.[2] Apatite occurs abundantly. Magnetite is present in irregular grains of considerable size and also as minute granules. The ground-mass consists of an ultimate base of clear isotropic glass thickly crowded with opaque and reddish brown granules, minute crystalline grains of pyroxene and, in places, with the mica above referred to.

Rocks unaffected by surface alteration form only a small portion of the Cheviot district. The dominant rocks are lavas and tuffs which must originally have been similar in composition and texture to modern andesites, but which are now in a more or less altered condition. The term porphyrite may be conveniently applied to these rocks but it must be distinctly remembered that the term has reference merely to secondary characters. It is simply equivalent to the expression altered andesite.

Now the Cheviot porphyrites differ from the andesites in having their felspars more or less decomposed, their ferro-magnesian minerals replaced by bastite, chlorite or other green decomposition products and also in frequently containing a certain amount of disseminated ferric oxide (ferrite). Freshly fractured surfaces are always dull (never resinous or vitreous) and of a purplish, reddish or dark bluish colour. The colour is dependent upon the state of oxidation of the iron-ores scattered through the mass. Two types of porphyrite have been recognized—pyroxene-porphyrite and mica-porphyrite.

A very typical pyroxene-porphyrite (the term pyroxene is used to cover both the monoclinic and rhombic minerals) is represented in Fig. 2, Plate XXXVII. This rock was originally a labradorite-enstatite-andesite. The ground-mass is a typical "mikrolithenfilz." Excellent examples of pyroxene-porphyrite may be obtained from almost any portion of the district occupied by volcanic rocks.

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(1) Bull. U. S. Geol. Survey, No. 28.

(2) As a large mass of granite occurs near the exposure of the above rock it is quite possible that the peculiarity in the felspar and the presence of the brown mica may be features due to contact metamorphism.

Mica-porphyrites appear to be less common than pyroxene-porphyrites. They are generally reddish purple or brick-red in colour. The porphyritic constituents are felspar (oligoclase?) and biotite. The brown biotite is usually more or less replaced by chlorite. Both the porphyritic felspars and the ground-mass appear red by reflected light in consequence of the large amount of ferric oxide scattered through the rock. The original structure of the ground-mass is often very difficult to determine in consequence of the large amount of alteration which has taken place. In some specimens, however, it becomes distinctly micro-granitic or micro-pegmatitic. This occurs however in dykes, and serves to connect the andesites with the diorites. In the typical andesites and porphyrites there is no recognizable quartz. The silica is latent, so to speak, in the highly acid glassy base. It is important to note that the mica-andesites are, as a rule, more acid than the pyroxene-andesites; so that, whenever the ground-mass of a mica-andesite becomes holo-crystalline quartz makes its appearance in considerable quantity.

It is important to note that no representatives of the hornblende-andesites or porphyrites have as yet been observed in the Cheviot district.

When the Cheviot porphyrites become vesicular the cavities are filled with opal, chalcedony, quartz and green earth. Beautiful agates are frequently found in the Coquet. These have been weathered out of the amygdaloidal porphyrites.

Bedded tuffs and agglomerates are associated with the andesites and porphyrites. They are composed of broken felspars, vesicular lapilli of andesite or porphyrite, and fragments of similar rocks without vesicles. The ground-mass, so to speak, of the tuffs which must have been composed of the finer volcanic material has been so altered that we can no longer recognize the nature of its constituent parts. The vesicles of the lapilli are filled with chalcedony and quartz. Apatite, ferrite and viridite are present in all specimens.

The volcanic eruptions which gave rise to the Cheviot andesites must have taken place in Lower Old Red Sandstone times.

The Lake District.—Mr. Ward [1] has proved that the Borrowdale series of this district is mainly composed of volcanic rocks of intermediate composition. He has also given us descriptions of the microscopic characters of the rocks. Dr. Sorby [2] has investigated many of the slates and established the fact that they are composed to a very large extent of fragmental volcanic material.

Owing to the great age of these rocks and to the fact that they have been affected by the post-Silurian earth-movements they are often found in a highly-altered condition so that it is often extremely difficult to make out their original characters.

A typical series of lavas and tuffs occurs at Falcon Crag and Brown Knotts in the neighbourhood of Keswick. This series has been described

(1) Q.J.G.S., Vol. XXXI. (1875), p. 406; and the Geology of the Northern Part of the Lake District: Memoirs of the Geological Survey, 1876.

(2) Q.J.G.S., Vol. XXXVI. (1880), Proceedings, p. 74.

in detail by Mr. WARD. The lavas often assume a vesicular character at their upper and under surfaces; the vesicles now being filled with calcite, chalcedony and green earth. The ground-mass is generally of a greyish blue colour. Porphyritic felspars and soft dark spots, representing the decomposed ferro-magnesian minerals may commonly be observed. The porphyritic felspars are generally so much altered as to give only aggregate polarization. Sometimes, however, the twin striation may be recognized. In form and relation to the ground-mass they are precisely like those of modern andesites. The porphyritic ferro-magnesian constituents are almost always replaced by green alteration products. That they were originally in most cases pyroxenes may be regarded as certain; probably enstatite and augite were both present. The typical ground-mass of these rocks was, as Mr. WARD has shown, a "mikrolithenfilz." Minute acicular microlites of felspar, pyroxene-granules, usually replaced by green alteration products, and magnetite grains, form the greater portion of this ground-mass. The alteration to which it has been subjected appears to have destroyed all traces of interstitial glass. We may reasonably conclude however, that such a substance was originally present. The above facts show beyond a doubt that the dominant variety of lava was a pyroxene-andesite. The widespread alteration to which the rock has been subjected now induces us to term it a pyroxene-porphyrite.

An interesting variety of this rock occurs behind the Lodore Hotel, near Grange, in Borrowdale (see WARD). It differs from the above type in containing no porphyritic constituents. The rock is of a greyish blue colour and very compact. It often breaks with a conchoidal fracture. Under the microscope it is seen to consist of minute lath-shaped felspars arranged with their long axes approximately parallel to each other; green alteration products, probably representing minute augite-granules, and small grains of magnetite. This rock is precisely similar in structure and composition to the ground-mass of the normal andesites and porphyrites. Among the secondary minerals present in the lavas of the Borrowdale series we may mention epidote and granular sphene.

Fragmental volcanic rocks form a large portion of the Borrowdale volcanic series. The size of the component fragments varies within wide limits. Owing to subsequent alteration it is difficult to determine with certainty the original characters of the fine-grained ash. An andesitic ash of the present day is usually composed of minute angular fragments of glass often bounded by concave outlines which represent fractured vesicles, broken felspar-crystals and crystals, either whole or fragmentary, of the ferro-magnesian constituents. It is highly probable that many of the Cumbrian ashes originally possessed a similar composition. If so their characters have been to a very great extent obliterated. The broken felspars may in many cases be recognized. The ferro-magnesian minerals have, however, been in almost all cases replaced by green alteration products. The minute glassy particles have been devitrified and their characteristic outlines are not often recognizable. The coarser fragmental rocks have preserved their original characters in a much more perfect

manner. Dr. SORBY describes specimens from Langdale. These are composed of fragments of "vesicular lava or imperfect pumice, the basis of which varies from perfect glass to a completely devitrified felsite, and often shows a perfect fluidal structure." Such a rock must evidently have been formed by the breaking up of a more or less glassy lava before the period of final consolidation. The same author states that "in other localities the ash must have contained a much more perfect pumice, and in others a considerable amount of augite, subsequently altered into a green fibrous mineral, which also entirely or partially fills what were originally cavities in the rock. Sometimes even in the same microscopical section we can trace a gradual passage from ash composed of particles large enough to be easily recognized to what appears to have been an extremely fine-grained volcanic dust, associated with fragments of true pumice." Many of the fragmental volcanic rocks in question have been converted into slates and in these cases the constituent particles have been so deformed that it is often impossible to determine their original characters.

In many parts of the Lake District and especially round the granite masses of Eskdale, Wastdale and Ennerdale there occur compact felstone-like rocks often more or less porphyritic about the origin of which it is difficult to be certain. Mr. WARD was led in the course of his mapping to regard these as highly altered ash-beds, but for details as to the evidence on this point the reader is referred to the original communications.

The following analyses taken from Mr. WARD's papers will give some idea of the chemical composition of the volcanic rocks of the Borrowdale series.

	I.	II.	III.	IV.
SiO_2	60·718	59·511	59·151	68·421
Al_2O	14·894	17·460	19·212	15·855
Fe_2O_3	1·405	1·271	·879	·172
FeO	6·426	4·926	5·192	2·855
CaO	6·048	5·376	5·208	2·016
MgO	1·909	1·801	1·909	·792
K_2O	2·354	3·705	2·933	3·338
Na_2O	2·843	3·093	4·217	5·627
FeS	·395	·604	·360	—
P_2O	·281	·115	·439	·204
SO_3	·103	·086	tr.	—
CO_2	1·660	1·569	tr.	tr.
Loss	·964	·483	·500	·720
	100·000	100·000	100·000	100·000

I. Pyroxene-porphyrite (Felsi-dolerite of WARD) Brown Knotts, near Keswick.
II. Pyroxene-porphyrite Iron Crag.
III. Probably a lava; close to granite of Lingmell Beck, near Wastdale Head.
IV. Coarse ash from Slight Side, about a mile from the granite (Sheet 98, S.W.)

It will be observed that the ashes are, so far as they have been analysed, more acid than the lavas.

Leicestershire.—Messrs. HILL & BONNEY [1] have shown that the pre-Triassic stratified rocks of Charnwood Forest are very largely composed of volcanic material and that many of them are true volcanic breccias. Lapilli of andesitic lava and broken felspar-crystals are frequently recognizable in the thin sections. The ferro-magnesian minerals have been generally decomposed, but in the rock occurring near the cottages east of the monastery, in the northern portion of the district, Messrs. HILL and BONNEY observed lapilli containing plagioclase and the black-bordered hornblende so characteristic of the hornblende-andesites.

North Wales.—Volcanic rocks of intermediate composition will probably be found to occur on a much more extensive scale than is at present recognized. Mr. TAWNEY[2] has shown that the hill of Carn Boduan in the Lleyn peninsula of Caernarvonshire is mainly composed of hornblende-porphyrite. The least altered rock is almost black in colour. The porphyritic constituents are plagioclase, green hornblende and a little augite. The ground-mass is formed of felspar-microlites, much dusty magnetite and a little interstitial glass. Apatite is abundant. Crystals of iron oxide are often associated with the hornblende. The freshest varieties of this rock almost deserve the name andesite. The mass appears to be intrusive in Ordovician strata.

Shropshire and Montgomeryshire.—Mr. WATTS[3] has described a series of andesitic lavas occurring in the Breidden Hills. They are interstratified with Ordovician sediments. The rocks are of a dark grey or dull greenish colour. The average specific gravity is about 2·66. The porphyritic constituents are felspar and pyroxene, the crystals of the former rarely exceeding 1in. in length, those of the latter being smaller. The ground-mass is a "mikrolithen filz." Owing to alteration it is difficult to be certain as to the presence of interstitial glass. The porphyritic felspars are often turbid in thin sections. The pyroxene is mainly rhombic; but monoclinic augite, often more or less altered to chlorite, is also present. The enstatite is green and evidently therefore somewhat altered. It resembles the enstatite (bastite?) of the pyroxene-porphyrite of Eycott Hill. Iron-ores are present. Brown hornblende was recognized in one or two slides.

South Wales.—Altered andesites occur at several points in South Wales but have not as yet received much attention. A pale-coloured andesitic or trachytic breccia is exposed near Trefgarn Bridge, Pembrokeshire, beneath shales which contain Lingula Flag fossils. A somewhat basic porphyrite occurs at Crab Hole near Dale, also in Pembrokeshire. Porphyrites also occur on Skomer Island but they belong to the border line between basic and intermediate rocks.

Scotland.—Rocks of the group now under consideration are very extensively developed in certain portions of Scotland. They constitute

(1) Q.J.G.S., Vol. XXXIV. (1878), p. 199
(2) G.M., 1882, p. 549.
(3) Q.J.G.S., Vol. XLI. (1885), p. 532.

large portions of the volcanic products of Lower Old Red Sandstone and early Carboniferous times. Those of the latter period have been described by Dr. GEIKIE in his Memoir on the Carboniferous Rocks of the Firth of Forth Basin.[1] They have been mapped as "felstones," "porphyrites" and "claystones." They form the thick terraced masses which range through the north of Ayrshire, Renfrewshire and Dumbartonshire to the Forth at Stirling. Similar rocks in Berwickshire, Roxburgh and Dumfries spread over wide areas at the base of the Calciferous Sandstone series. The ground-mass is usually some shade of red or brown, varying from a dark chocolate or purple tint to a pale yellow or nearly white; greenish and bluish shades being less common. In this ground-mass crystals of felspar porphyritic more or less decomposed are very common.

Amygdaloidal varieties of the rock may frequently be observed. The specific gravity ranges from 2·6 to 2·7. Under the microscope the more or less decomposed felspars are seen to have contained the inclusions characteristic of the andesites. The ground-mass is an aggregate of minute felspar microlites and grains and crystals of magnetite. Pyroxene is sometimes recognizable as granules and more rarely as crystals. It is very subordinate to the felspar and as a rule has been replaced by secondary products. Ferric oxide is usually present in greater or less quantity. Hence the prevailing reddish tints. Good illustrations of this type of rock occur in the Garlton Hills of Haddingtonshire.

Mr. DURHAM and Prof. JUDD have described some very interesting and comparatively unaltered rocks occurring in the north-eastern portion of the county of Fife, near the Tay Bridge.[2] They belong in all probability to the Lower Old Red Sandstone period. The rock of Northfield quarry is dark in colour (resembling a basalt) and without porphyritic crystals. The main mass of the rock is composed of felspar microlites, pyroxene-granules and a glassy base containing globulites, trichites and belonites. In this ground mass lie groups of pyroxene crystals the angles of which are mostly rounded. Two varieties of pyroxene were recognized; monoclinic (augite) and rhombic (enstatite). The specific gravity of the rock was found to be 2·68.

The rock of Causeway Head is more distinctly crystalline than the above. Under the microscope it is seen to consist essentially of large microlites of felspar, a rhombic pyroxene and some grains of magnetite. The pyroxene sometimes occurs in fairly well-formed prismatic crystals and sometimes as rounded or irregular grains. Some of the pyroxene may be monoclinic. Biotite occurs as an accessory constituent. There are no porphyritic constituents in this rock but the pyroxene grains are sometimes found grouped round the magnetite in such a way as to give the rock a glomero-porphyritic structure. The rock has a specific gravity of 2·79 and is of a dark colour and therefore basaltic in habit. The specific gravity and general appearance both indicate that we are dealing with a somewhat basic rock. Indeed the principal difference between this rock

(1) **Trans. Roy. Soc. Edin. 1880 p. 486.**

(2) Q.J.G.S., Vol. XLIII. (1886), p. 418.

and the norites is one of texture. The norites are granitic—this rock is trachytic.

Between Scoggieside Farm and the Tay Bridge is a remarkable volcanic breccia. The dominant rock of this breccia is red in colour and has a specific gravity of 2·58. It is composed of a compact hornstone-like ground-mass in which lie porphyritic felspars, probably oligoclase, and a few crystals of biotite. Under the microscope the ground-mass is seen to be much decomposed. Traces of flow structure may, however, be detected and microlites of felspar are common. The rock appears to be a mica-oligoclase-porphyrite. Mr. DURHAM speaks of it as a dacite, but Prof. JUDD does not mention the occurrence of quartz among the porphyritic constituents. Quartz does, however, occur in the "porphyry" of Lentrethen in Forfarshire and Prof. JUDD states that this "porphyry" is allied to the rock in question. Associated with the mica-oligoclase-porphyrite is a remarkable vitreous rock. In its unaltered condition this is of a dark grey almost black colour and possesses a resinous or sub-vitreous lustre. Its specific gravity is about 2·31 and its silica percentage 67·21. The porphyritic constituents are plagioclase and biotite. The plagioclase crystals are often broken; the detached fragments of one individual often lying near each other in the same slide. The biotite is characterized by intense pleochroism and is probably similar to that of the Lentrethen dacite hereafter to be described. The ground-mass is composed of a glassy base, felspar microlites (probably orthoclase), trichites and globulites. The base shows the most exquisite perlitic structure. Prof JUDD describes this remarkable rock as a mica-dacite glass. He found that portions when heated before the blow-pipe swelled up in "cauliflower-like excrescences till they attained a bulk at least eight or ten times that of the original fragments." The resulting product was found to be a white pumice which floated on water.

The vitreous rock decomposes in the field into a white powder in which the felspar crystals remain intact. This powder loses 12·4 p. c. of its weight when dried at 110° C. and another 10·1 p. c. on ignition. It is regarded by Prof. JUDD as bearing the same relation to the acid glasses as palagonite does to the basic glasses. Mr. DURHAM shows that the vitreous rock occurs in nests in the mica-oligoclase porphyrite. In the majority of cases these nests are now simply represented by hollows containing more or less of the white powdery substance above referred to. It is only under exceptionally favourable circumstances that the unaltered dacite glass can be obtained.

As the "porphyry" of Lentrethen has been referred to and as the dominant felspar of this rock appears to be plagioclase it may be described in this connection, though in chemical composition it is in all probability an acid rock. The specimen on which the following remarks are based was given to the author by Mr. RUTLEY. The rock is of a bright red colour. Glassy felspar, quartz and both white and black micas (the latter largely predominating) may be easily recognized with a hand lens. The ground-mass gives the colour to the rock. In general appearance the specimen closely resembles many rhyolites. Under the microscope the felspars are seen to be perfectly fresh and very free from inclusions. They frequently show

multiple twinning. Quartz is fairly abundant and often shows the outlines due to corrosion, so characteristic of the rhyolites and quartz-felsites. The brown mica occurs in hexagonal tables. It is very deeply coloured. Extremely thin flakes, examined in convergent light, show that the mineral is biaxial with a wide but somewhat variable optic axial angle (sometimes over 73° in air). When examined in parallel light with the polarizer only a marked dichroism is seen ; β rich yellowish brown, γ deep shellac brown. In thin slices of the rock sections at right angles to the principal cleavage are yellowish brown for rays vibrating at right angles to the cleavage (a, axis) and opaque for rays vibrating parallel to the cleavage. The pleochroism in extremely thin sections may therefore be defined as follows :—a, pale yellowish brown ; β, rich yellowish brown ; γ, deep shellac brown. Absorption $a < \beta < \gamma$. In convergent light the dispersion of the optic axes is very marked $\rho < \upsilon$. The biotite plates have been bent and crumpled by movements in the magma and also more or less corroded and frayed at the edges. The white mica occupies the same relation to the ground-mass as the black mica. It appears to be an independent mineral. It is colourless and devoid of pleochroism. Its optic axial angle in air is about 56°. The occurrence of white mica (apparently muscovite) in a rock of this character is exceptional. The ground-mass is mainly composed of a somewhat granular isotropic substance deeply coloured in places by stripes and patches of ferrite. The outlines of the ferrite patches in many instances suggest the conclusion that they represent corroded biotite. The rock shows a marked fluxion structure due to the relation of the ferrite patches to the large porphyritic constituents. Other specimens of the Lentrethen "porphyry" which have come under the author's notice differ from the above in being more or less decomposed.

Volcanic rocks of intermediate composition are extensively developed in Glencoe and on the summit of Ben Nevis.[1] The summit of Ben Nevis is formed of a dark bluish grey rock in which small porphyritic felspars are easily recognizable. Under the microscope this rock is seen to be a very typical and only slightly altered hornblende-andesite (see Fig. 1, Plate XXXVII). The plagioclase crystals have the characteristic forms and inclusions. The hornblende occurs somewhat sparingly; a, pale brown ; β, deeper shade of brown ; γ, greenish brown. The pleochroism is not strongly marked. The crystals often possess black borders and sometimes the corrosive action has been so great as to leave merely aggregates of magnetite which preserve more or less the forms of the original crystals. The ground-mass is thickly strewn with minute dusty particles. Examined with a high power the indistinct outlines of extremely minute felspar microlites may be often recognized. The microlites are so closely crowded together that no interstitial glass is recognizable. This rock is extremely interesting as it is at present the only good instance of a hornblende-andesite known in the British Isles. It is almost certainly of newer Palæozoic age.

(1) See Prof. Judd, Q.J.G.S., Vol. XXX., p. 291.

Augite-porphyrites (altered augite-andesites) occur in Glencoe. One type of rock is reddish in colour and distinctly porphyritic. The porphyritic constituents are turbid felspar and augite. The felspars, in the slides examined, show no trace of individual action; they are almost opaque. The augite occurs as grains rather than as crystals and is often perfectly fresh. It is almost colourless. Green pseudomorphs probably representing a second bisilicate are also present. The ground-mass is so crowded with granules and flecks of opacite, viridite and ferrite that it is impossible to determine its original character. Another type of rock from the same locality, represented by a slide lent to the author by Mr. ALLPORT, differs from the above in having a ground-mass composed of a micro-crystalline aggregate of quartz and turbid felspar. In the character of their ground-masses these rocks differ from the typical andesites and approximate to the felsites.

Two other slides of holo-crystalline rocks, allied to the above, from the same locality have also been lent to the author by Mr. ALLPORT. One shows turbid plagioclase often containing granules of epidote, greenish idiomorphic hornblende more or less changed to chlorite, grains of iron-ore and a micro- or crypto-crystalline ground-mass (hornblende-porphyrite). The other is not conspicuously porphyritic; it is composed of large felspars usually giving lath-shaped sections, augite, hornblende, biotite and a small amount of quartz which fills up the spaces between the felspars. This rock might be described as an augite-biotite-diorite. It is probably merely a local modification of the andesitic rocks.

Holo-crystalline rocks intermediate in texture between the diorites and andesites occur in Glen Etive. The interstitial matter in these is micro-pegmatite.

Hornblende-biotite-porphyrite with a micro-crystalline ground-mass occurs also at the Falls of Bruar, near Blair Athole. The plagioclase of these rocks is often crowded with scales of white mica.

A very remarkable and somewhat exceptional rock is found associated with the quartzite of Canisp in Sutherlandshire. Specimens in the writer's possession show large crystals of plagioclase (oligoclase or oligoclase-albite) in a reddish matrix. Under the microscope augite and biotite may be also detected amongst the minerals of first consolidation. The augite may be colourless or green. Sometimes the green variety forms a zone round the colourless variety, the surface of separation being sharp and well defined. When this is the case the two varieties possess slightly different optical properties. Thus, in a section, approximately parallel to the clino-pinacoid, the extinction angle in the colourless kernel was 34°, that in the green zone 40°. The green variety does not appear to be the result of the alteration of the colourless variety. It is worthy of note that green augites of this type occur in acid rocks. The biotite is generally more or less altered to chlorite. The ground-mass is a micro-crystalline aggregate of quartz and turbid felspar. The rock may be described as a biotite-augite-oligoclase-porphyrite.

Certain portions of this mass of rock contain brick-red crystals of

orthoclase [1] and sometimes the orthoclase is seen to be surrounded by a zone of plagioclase. A polished slab illustrating this zoning of orthoclase by plagioclase is preserved in the British Museum. Both the orthoclase and plagioclase have been analysed by Dr. HEDDLE.[1]

We have now referred at sufficient length to what may be termed the normal plagioclase-rocks from which nepheline and leucite are absent. The somewhat abnormal rocks generally known as the mica-traps will be considered by themselves.

(1) Trans. Roy. Soc. Edin. XXVIII., 1879, p. 2.

CHAPTER IX

GROUP C.

Nomenclature.

ROCKS in which orthoclase or sanidine constitute the dominant felspathic constituent are for the most part of acid composition. The granites represent the granitic texture, some of the quartz-felsites represent a kind of intermediate texture, the liparites represent the trachytic texture. The obsidians and pitchstones constitute the vitreous members of the same group. While recognizing the fact that most of the orthoclase-bearing rocks are of acid composition, it must not be forgotten that, occurring on the outskirts, so to speak, of the main group, are rocks of intermediate and even basic composition. Our classification based primarily on Bunsen's law breaks down, therefore, if we endeavour to apply it in a perfectly rigid manner. Various names have been given by different writers to different varieties of rocks in which orthoclase is or is supposed to be the dominant felspar. Some of the most important of these are granite, granitite, granulite pegmatite, aplite, eurite, felsite, quartz-felsite, felsite-porphyry, elvanite, quartz-porphyry, granophyre, felsophyre, vitrophyre, trachyte, quartz-trachyte, liparite, rhyolite, nevadite, syenite, augite-syenite, monzonite.

Granite.—This is a very old term said to have been used as far back as 1596 by Cesalpinus. As now used it implies that the rock is holo-crystalline and that it contains orthoclase, quartz, and a third mineral, generally one of the ferro-magnesian compounds. Plagioclase is very commonly present. If we regard the term granite as connoting the presence of the granitic texture and the minerals felspar (mostly orthoclase) and quartz we may subdivide the group according to the nature of the other minerals which play an important part in the composition of the rock. We thus have as principal types—

MUSCOVITE[1]-GRANITE.

BIOTITE-GRANITE.

HORNBLENDE-GRANITE.

AUGITE-GRANITE.

The above types, with the exception of the second, are rarely found in

(1) The term muscovite is here used as synonymous with white mica and biotite as synonymous with black mica. White magnesian micas are not known to occur in the granites.

what may be termed the ideal condition. Two or more of the distinguishing minerals are usually found occurring together in the same rock. Thus we have muscovite-biotite-granites; biotite-hornblende-granites, and biotite-augite-granites. Augite-bearing granites are comparatively rare.

Granitite.—This name was proposed by G. ROSE for a granite containing much oligoclase and a black mica, but no original white mica. It is so used by most German authors.

Granulite.—French authors use this term for an eruptive granite containing both micas. Thus the Cornish and Aberdeen granites would be termed granulite by French petrographers. German authors use the same name for a rock of doubtful origin in which garnet is frequently present as an accessory constituent.

Aplite.—This name has been applied to a rock composed almost entirely of quartz and felspar. ROSENBUSCH proposes that it should be used so as to include the muscovite-granites. Aplite or muscovite-granite is not known to form independent rock masses of considerable extent. It occurs rather as veins and dykes, or as the apophyses of ordinary granites.

Pegmatite.—This name was applied by HAÜY to the definite intergrowth of quartz and felspar otherwise known as graphic granite. NAUMANN altered the signification of the term and applied it to extremely coarse aggregates of quartz, orthoclase and mica. Pegmatite (HAÜY) and pegmatite (NAUMANN) are often found together. They occur rather as segregations than as independent masses of eruptive origin.

Felsite, Eurite, Petrosilex.—These terms are practically synonymous. They have been applied to compact, stony rocks the mineralogical composition of which cannot be ascertained by examination with the naked eye or with a lens. These rocks are anhydrous (or nearly so) and except in this respect agree in composition with the acid glassy lavas. The first term was proposed by GERHARD (1814), the second by DAUBISSON (1819), the third by BROGNIART. We shall use the first term only. Many of the felsites have been shown by RUTLEY and BONNEY to be devitrified obsidians and pitchstones. Such felsites represent the glassy lavas of the early geological periods.

Quartz-felsite.—This term has come into extensive use in this country for a rock containing porphyritic crystals of quartz and felspar in a matrix of felsite.

Quartz-porphyry.—This term is used on the Continent for pre-Tertiary porphyritic rocks of acid composition. It includes the quartz-felsite of British petrographers and also the porphyritic pitchstones and obsidians of pre-Tertiary age.

Felsite-porphyry.—This term is also extensively used on the Continent for any porphyritic rock with a felsitic ground-mass. It includes the quartz-felsites and also rocks that may be termed ortho-felsites (orthophyres of some authors)—that is rocks containing porphyritic orthoclase without porphyritic quartz.

Elvanite.—This is derived from a Cornish miners' term It includes

rocks which are better designated by such terms as felsite, quartz-felsite, ortho-felsite, and micro-granite.

Granophyre, Felsophyre, Vitrophyre.—These three terms were introduced by VOGELSANG for different varieties of quartz-porphyry. The rocks designated by the first two terms can only be distinguished by the use of the microscope. The granophyres of VOGELSANG are rocks which possess a holo-crystalline ground-mass; the felsophyres are rocks with a crypto-crystalline or micro-felsitic ground-mass. ROSENBUSCH has shown that the granophyres of VOGELSANG may be divided roughly into two groups—(1) those with a micro-crystalline or micro-granitic structure and (2) those with a micro-pegmatitic or pseudo-spherulitic structure. He proposes that the rocks of the former group should be termed micro-granites and that the term granophyre should be limited to those of the latter. In using the term granophyre it is therefore necessary to state which author is followed. The term vitrophyre is applied to the quartz-porphyries with a vitreous ground-mass.

Trachyte.—This name was introduced by HAÜY, but his definition is not of much use in fixing the modern sense of the term. It is now generally applied to rocks containing porphyritic crystals of sanidine in a felsitic or vitreous ground-mass. From this point of view the rocks to which it is applied differ from the quartz-free felsophyres (orthophyres) merely in the fact that the large felspars are sanidine instead of orthoclase. As used by RICHTOFEN and SZABO the term includes the andesites of most modern authors.

Liparite, Rhyolite, Quartz-trachyte.—These terms are practically synonymous. They are applied to the typical volcanic rocks of acid composition. Such rocks, in their unaltered condition, contain as a rule porphyritic crystals of sanidine and quartz embedded in a micro-crystalline, crypto-crystalline, micro-felsitic or vitreous ground-mass. The ferro-magnesian minerals occupy a very subordinate position in the composition of these rocks. Some authors use liparite as the group name; others use rhyolite. The more recent liparites or rhyolites frequently contain a glassy base. The corresponding rocks of the earlier geological periods more frequently possess a micro- or crypto-crystalline ground-mass which, however, can be proved in many cases to owe its double-refraction to the devitrification of a glassy base.

Nevadite.—This term was introduced by RICHTOFEN for certain liparites or rhyolites which somewhat resemble granite. It has been shown by HAGUE and IDDINGS that, in the typical nevadites, this resemblance is superficial and due to the fact that the porphyritic crystals are exceptionally abundant. Just as certain basalts (*e.g.*, that of Dunsapie Loch near Edinburgh) somewhat resemble gabbros in appearance in consequence of the extraordinary abundance of their porphyritic constituents so do certain liparites resemble granites. The resemblance in both cases is superficial and disappears on careful examination.

Syenite.—This term is said to have been used by PLINY for the rock occurring at Syene (Assouan) in Egypt. It was subsequently applied to

the rock of the Plauenschen Grunde near Dresden by WERNER. The Egyptian rock is a hornblende-biotite-granite: the Saxon rock is essentially composed of orthoclase and hornblende. Plagioclase, quartz, biotite and sphene occur as accessories. The term is now generally applied to orthoclase-bearing rocks in which quartz is present only in very small quantity and may be absent altogether. In this sense the syenites are rocks of intermediate composition so far as silica percentage is concerned, but they differ from the normal intermediate rocks in having more potash than soda. The structure of all syenites is granitic. Mineralogically syenite is the plutonic representative of trachyte and, like trachyte, it does not appear to be a very widely distributed rock. The term has been somewhat loosely used in this country. It is doubtful whether any rocks answering to WERNER's type have been recognized.

Augite-syenite.—This term was introduced by VON RATH for certain rocks of granitic texture which consist of orthoclase and augite, together with small quantities of plagioclase, iron-ores and sphene. The type-rocks occur near Predazzo in the Tyrol. They are associated with plagioclase-augite rocks of similar texture (diabase of VON RATH, gabbro of most authors) into which they pass by regular gradation. The term *monzonite* is sometimes used instead of augite-syenite.

Mica-syenite.—This term is applied to granitic rocks essentially composed of black mica and orthoclase. Mica-syenites are comparatively unimportant so far as distribution is concerned.

Enstatite-syenite.—As we have hornblende-syenites (syenites proper) augite-syenites and mica-syenites we should naturally expect, from analogy with other rock-groups, to find a rock answering to this term. Mr. WILLIAMS [1] has recently described such a rock under the term Norite. It occurs in the Cortlandt series and consists of orthoclase, andesine and hypersthene, together with small quantities of biotite, apatite and iron-ore.

Obsidian and Pitchstone.—These terms are applied to the glassy forms of the acid magma.

So far we have been referring more especially to the terminology of comparatively unaltered rocks. Many felsites and felsite porphyries (felsophyres) are, it is true, devitrified obsidians, pitchstones and vitrophyres: but we are at present unfortunately unable to separate these in all cases from the corresponding rocks in which the double-refraction of the felsitic matter is a consequence of the actions accompanying solidification (primary devitrification). The various agencies of metamorphism produce changes in the rocks of the present group as in those of every other group, and some special names have been applied to special types. In many cases the names were introduced before the true nature of the rocks was recognized, so that the terminology of the metamorphic rocks is more than usually defective. Again, it may be regarded as certain that similar

(1) A.J.S. Vol. XXXIII., 1877, p. 138.

results may be produced by the metamorphosis of rocks of dissimilar origin. We may mention the following as terms that have been applied to rocks produced by the metamorphosis of acid igneous rocks; but it must not be supposed that all rocks to which these terms have been applied are necessarily of similar origin:—greisen, luxullianite, trowlesworthite, porphyroid, gneiss, granulite hälleflinta mica-schist.

Greisen.—This term is applied to a rock essentially composed of quartz and mica. Topaz occurs so frequently that it may almost be regarded as an essential constituent. The rock is found in tin-stone regions and appears to be a granite metamorphosed in connection with exhalations of fluoric acid.

Luxullianite.—This term has been applied to a remarkable variety of tourmaline-granite occurring in the form of large blocks near the village of Luxullian in Cornwall. The rock has been described by Prof. BONNEY.[1] It consists essentially of reddish orthoclase, tourmaline and quartz, and may be regarded as a granite metamorphosed in connection with exhalations of boracic and fluoric acids.

Trowlesworthite.—This name was introduced by Mr. WORTH. The rock has been described by Prof. BONNEY[2]. It consists of orthoclase tourmaline, fluor and a little quartz. The fluor takes the place of the quartz in the ordinary granite.

Porphyroid.—This term has been applied to certain rocks which are intimately associated with Palæozoic sediments in Thuringia, the Hartz, the Taunus and the Ardennes. They occur as lenticular masses and as sheets and frequently exhibit a kind of passage into the surrounding rocks. This apparent passage is often due to the fact that the marginal portions of masses of porphyroid are markedly schistose; the planes of schistosity running parallel with those of the adjacent rock. Many of the porphyroids are distinguished from the porphyries merely by the presence of wavy planes occupied by sericite or some other micaceous mineral (flaser-porphyroid). By an increase in the number of these planes and by a corresponding increase in the micaceous mineral the rock passes over into a schistose porphyroid and finally into a sericitic schist.

The porphyritic constituents of the porphyroids are the same as those of the porphyries, viz.: orthoclase, plagioclase and quartz. The ground-mass may be massive or schistose. Hand specimens from the central portions of a mass of porphyroid are often undistinguishable from a quartz-porphyry whereas the marginal portions of the same mass may exhibit a most marked schistosity. With the coming in of schistosity the angles of the large porphyritic felspars become more or less rounded off and the crystals themselves cracked at right angles to the direction of stretching[3].

Porphyroids of the above type shade into hälleflinta-like rocks by the

(1) Min. Mag., Vol. 1., p. 215.

(2) Trans. Roy. Geol. Soc., Cornwall, 1884.

(3) This direction is the longest axis of the strain-ellipsoid. It is clear that the schistose porphyroids of the type above referred to are merely deformed masses of quartz-porphyry.

disappearance of the porphyritic constituents and of the flaser-structure. It appears from the above description that the typical porphyroids (*e.g.*, those of the Ardennes) bear the same relation to quartz-porphyries that the "schistose greenstones" do to dolerites. They are for the most part acid rocks that have been affected by dynamic metamorphism.

Gneiss.—This is a term used by the miners of Saxony to designate the country rock in which the ore-deposits of the Erzgebirge occur. It has been extended by geologists to rocks of very variable structure and composition. Most gneisses resemble granite in composition. The term has, however, been applied to rocks allied to syenite, diorite and gabbro. In all cases it implies a more or less marked parallel structure in the arrangement of the constituents. Some writers maintain that the term should be used merely in a structural sense and that the different mineralogical varieties should be designated by appending the name of the corresponding plutonic rock. We should thus have granite-gneiss, diorite-gneiss, gabbro-gneiss, etc. Rocks to which the term gneiss is now applied may be separated into three groups:—(1) Eruptive rocks in which the parallel structure dates from the time of consolidation; (2) rocks in which the parallel structure is of secondary origin and connected with the deformation of rock-masses after consolidation; and (3) rocks of doubtful origin. The third group is the most important so far as distribution is concerned. It includes the banded gneisses, so common in the Archæan areas, and supposed by some to have been produced only in Archæan times. The rocks of the first group, so far as they are of acid composition, are of course merely varieties of granite. The rocks of the second group are in most cases metamorphosed granites. In some cases they may be metamorphosed sediments of granitic composition (arkoses) or metamorphosed, possibly we ought to say re-metamorphosed representatives of the third group. It thus appears that only a limited portion of the rocks to which the term gneiss is applied can be regarded as metamorphosed granites.

Mica-schist.—This term, like the last, is of very wide application and includes rocks of diverse origin. It is applied to holo-crystalline foliated rocks essentially composed of mica and quartz. The minerals of a typical mica-schist are for the most part authigenic. The margins of granitic masses in areas that have been affected by dynamic metamorphism, posterior to the intrusion of the granite, often exhibit transitions from normal granite through gneiss to mica-schist. The mica-schist in these cases must be regarded as the result of the deformation of masses of granite. It is a further stage of the process which has given rise to certain varieties of gneiss. The mica has been developed at the expense of the felspar. Mica-schists have also been produced by the metamorphosis of sedimentary rocks and rocks of doubtful origin. Apart from field-evidence we have at present no decisive tests for distinguishing between the different types of mica-schist.

Granulite.—The so-called granulites of Saxony are regarded by LEHMANN as eruptive rocks of granitic character that have been metamorphosed by plastic deformation subsequent to solidification. The term

granulite has reference rather to texture than to composition. The main mass of the normal granulite is an aggregate of small grains of quartz and felspar. Under crossed nicols it presents the appearance of a mosaic. The adjective granulitic is frequently applied to such a mosaic. Garnet is commonly present in the Saxon granulites. The normal granulite (weiss-stein) which is an acid rock is associated with the so-called trap-granulite (pyroxene granulite), a basic rock, essentially composed of pyroxene (rhombic and monoclinic) plagioclase and iron-ore.

Hälleflinta.—This is a Swedish term. Typical hälleflinta is a hard compact rock with a banded structure and having approximately the composition of felsite. Rocks of diverse origin are grouped under this term. Those associated with the normal granulite of Saxony are held by LEHMANN to be of metamorphic origin.

The following table will assist the reader in understanding the sense in which the most important terms are used in the present work :—

ACID ROCKS.

Volcanic.	Liparite, Rhyolite, Vitrophyre, Obsidian, Pitchstone and many felsites.	
Intermediate.	Certain felsites and felsite-porphyries.	Felsophyre. Granophyre. Micro-granite.
Plutonic.	Certain Granites and Gneisses.	

METAMORPHIC ACID ROCKS.

Volcanic.	Certain felsites (devitrified rhyolites, obsidians and pitchstones). Certain porphyroids and sericitic schists (metamorphosed liparites and liparite-tuffs.)
Intermediate.	Certain porphyroids (metamorphosed quartz felsites).
Plutonic.	Certain gneisses and mica-schists (metamorphosed granites); also such rocks as greisen and luxullianite.

SUB-ACID ROCKS.

Volcanic.	Trachyte.
Intermediate.	Ortho-felsite or Orthophyre.
Plutonic.	Hornblende-syenite (syenite proper), Augite-syenite, Mica-syenite.

THE CONSTITUENTS OF ROCKS OF GROUP C.

Monoclinic felspar.—In the plutonic and intermediate rocks this felspar is generally more or less turbid; in the volcanic rocks it is frequently glassy. The term orthoclase is used to cover both varieties; the term sanidine is limited to the glassy variety.

When two generations of orthoclase are present the individuals of the first generation, except in so far as they have been broken by mechanical movements either during or subsequent to consolidation, are idiomorphic. The most important forms are P (001); M (010); l (110); x ($\bar{1}01$), and y ($\bar{2}01$).

The crystals may be either tabular in consequence of the conspicuous development of *M* (this is the most common form in British rocks) or columnar in consequence of the equal development of *P* and *M*, and the elongation of the crystal in the direction of the clino-diagonal axis. In the columnar crystals the most common terminal forms are *l* and *y*. The most perfect cleavage is parallel to *P*, but that parallel to *M* is often almost as perfect. There is also an imperfect cleavage parallel to *l* (110) and in sanidine a tendency to break along planes roughly parallel to the ortho-pinacoid (100). The cleavages are often not recognizable in thin sections. Zonal structures are frequently seen in the porphyritic crystals of the granitic and trachytic rocks; they are, however, as we should naturally expect, much more marked in the latter than in the former. The porphyritic crystals of the trachytic rocks are often completely honeycombed by inclusions of the ground-mass in the manner already described in speaking of the plagioclase-crystals of the trachytic rocks of basic and intermediate composition.

Twinning on the Carlsbad plan is very common. In this case the vertical axis is the twinning axis. Two adjacent individuals interpenetrate or else the face of composition is the clino-pinacoid. The basal cleavages of the two halves do not coincide and this produces the well-known macroscopic appearance indicative of twinning on this plan. Thin sections of a Carlsbad twin out of the zone 100: 001, extinguish simultaneously in both halves when the trace of the clino-pinacoid (usually the face of composition) lies parallel with the principal section of one of the nicols. This, as already stated, is one of the most useful tests in distinguishing between orthoclase and plagioclase under the microscope. In normal orthoclase the optic axial plane is at right angles to the plane of symmetry. Cleavage flakes parallel to M are at right angles to the obtuse bisectrix which is positive ($b=\gamma$). Sections parallel to the ortho-pinacoid (100) give straight extinction, and show in convergent light the negative bisectrix. The bisectrices for different colours are dispersed in a plane parallel to M, but this dispersion cannot be recognized in the ordinary thin sections. The optic axial angle varies greatly in different varieties of orthoclase. In orthoclase proper it is large (in air 112°–125°); in some varieties of sanidine it is very small indeed, the crystal appearing almost uniaxial. Des Cloiseaux has shown that by heating a section of orthoclase the optic axes may be made to approach and finally to expand in the plane of symmetry. If the temperature be raised above 500° C. the original positions of the axes are not recovered on cooling—the ellipsoid of elasticity is permanently deformed. The sanidine crystals in liparite tuffs are often found to have their optic axial plane in this abnormal position. It seems probable, therefore, that the variability in the optical characters of different varieties of orthoclase is largely due to physical causes operating after the development of the crystals. In twinning on the Carlsbad plan the optic axial plane in the one half lies parallel with that in the other; in twinning on the Baveno plan the optic axial plane in one half is at right angles to that in the other. Intergrowths of plagioclase and orthoclase may frequently be observed. They are much more common in the granitic than

in the trachytic rocks. In the latter they usually take the form of zoning and it is an interesting fact that no general rule can be laid down as to the order of development of the two species. Sometimes orthoclase is found surrounding plagioclase (Mont Dore, trachyte), at other times plagioclase is found surrounding orthoclase (porphyrite, Canisp). In all such cases the plagioclase appears to be oligoclase or oligoclase-albite.

In the granitic rocks and in the gneissose rocks of corresponding composition the intergrowths take the form of perthite and micro-perthite. Sections of orthoclase then exhibit a fibrous structure. Those parallel to M show a number of narrow and somewhat irregular strips or patches arranged with their longest axes parallel with the vertical axis of the crystal. These patches extinguish at a different angle to the main mass of the crystal and often possess lamellar twinning. Sections parallel to P show a less regular arrangement in the interpositions. The plagioclase appears in all cases to be either albite or oligoclase. The intergrowths of the above type may be observed on all scales of magnitude from macroscopic perthite down to the finest micro-perthite. It probably also occurs on an ultra-microscopic scale. LEHMANN regards micro-perthite as a secondary structure arising in connection with the metamorphosis of soda-orthoclase.

The specific gravity of orthoclase is less than that of any other felspar (2·54-2·59). The typical orthoclase-molecule is represented by the formula K_2O, Al_2O_3, $6SiO_2$. Analyses invariably show a certain amount of Na_2O. This Na_2O is present in a molecule of the albite type. The substance analysed may consist of a macroscopic, microscopic or ultra-microscopic intergrowth of typical orthoclase and typical albite; or of typical orthoclase and some soda-lime felspar.

The orthoclase of the second generation in porphyritic rocks may be idiomorphic or allotriomorphic. In the former case it rarely occurs in forms which give elongated lath-shaped sections. Square or nearly square sections bounded by traces of the faces P, M and y, are the most common. In holocrystalline rocks the relation of the quartz to the orthoclase is a matter of considerable importance. The experience of the author does not bear out the view that any rigid rule can be laid down to express the order of crystallization of these two minerals. Sometimes the orthoclase precedes the quartz, sometimes the two minerals crystallize simultaneously (granophyres), and sometimes the orthoclase plays the rôle of ground-mass to quartz grains which show more or less definite boundaries.

In the non-porphyritic granites it is generally impossible to recognize two generations of orthoclase. In these rocks the orthoclase rarely shows good crystalline form. It has crystallized approximately at the same time as the quartz and, where micro-pegmatitic structures have not been developed, the two minerals have mutually interfered with each other.

The normal alteration of orthoclase is accompanied by the development of scaly or granular matter. The scales may often be definitely recognized as a white micaceous mineral (sericite or muscovite) possessing high double refraction. The development of this scaly and granular matter is very

frequently referred to as kaolinization, and it seems probable that much of the granular matter may be closely allied to kaolin in composition. The decomposition products after orthoclase are often coloured red by ferric oxide. Sometimes they are distributed irregularly through the mineral; at other times the mica flakes have been more especially developed along the cleavage planes. Dr. SORBY has pointed out that the ground-mass of some of the Cornish elvans (quartz-felsites) is mainly composed of quartz and a micaceous mineral. It seems probable that this mica is a secondary product developed at the expense of the original orthoclase. Epidote granules are not unfrequently developed in connection with the alteration of orthoclase. Under exceptional circumstances orthoclase may be wholly or partially replaced by one or more of the following minerals—quartz, tourmaline, cassiterite, topaz.

Under the influence of dynamic metamorphism, orthoclase is sometimes replaced by a fine-grained mosaic of differently orientated individuals; at other times, and especially when a shearing movement takes place along definite planes, it gives rise to white mica which may take the form either of somewhat irregular crystalline scales or of a fine-grained aggregate of irresolvable individuals. The felspar-mosaic is often developed round the margins of the larger individuals, portions of which may remain as more or less porphyritic elements in a ground-mass of granulitic texture (mortar-structure, mörtel-structur, TÖRNEBOHM). The effects of dynamic metamorphism are best studied in rocks of granitic texture. When the felspar is replaced by a mosaic the quartz is affected in the same way so that the granulitic mass is usually an aggregate of quartz and felspar. Sometimes the individuals of the secondary aggregate of quartz and felspar are so minute as to be incapable of definite recognition. The aggregate must then be described as crypto-crystalline.

Microcline.—This mineral is common amongst the granites with two micas, rare in the biotite- and hornblende-granites, and almost entirely absent from the trachytic rocks of acid composition. Where it occurs as a normal constituent of the rock it is always without crystalline outline and is stated by ROSENBUSCH to be generally of later date than the orthoclase in the same rock. It is, however, frequently found intergrown with this mineral. Microcline with crystalline outline is found in granites with drusy cavities and the forms are analogous with those of orthoclase. The most striking feature of microcline is its polysynthetic structure. Cleavage flakes or sections parallel to P show this structure in great perfection. The mineral is seen to be made up of narrow and more or less spindle-shaped lamellæ which intersect approximately at right angles and thus produce the well known cross-hatching. The lamellæ parallel to the edge P : M in flakes parallel to P extinguish at angles of 15° on either side of the line of separation. They correspond to twinning on the albite plan. The second set of lamellæ is generally regarded as due to twinning on the pericline plan. The lamellæ of microcline are rarely so sharp and well defined as those of the other triclinic felspars and there is almost always a tendency to a spindle-shaped form in sections at right angles to the planes of lamella-

tion. Sections parallel to the macro- and brachy-pinacoids show only one set of lamellæ and these planes correspond, therefore, approximately to the faces of composition. The want of persistence in individual lamellæ is strongly marked in these sections. Irregular patches of albite or oligoclase are almost always found intergrown with microcline so that the M faces and the vertical axes approximately coincide. These are best observed in cleavage flakes or sections parallel to P where the even lamellation of the albite is in strong contrast to the cross-hatching of the microcline. The chemical composition, refraction, double-refraction and specific gravity are approximately the same for microcline as for orthoclase. According to M. Lévy the two minerals are identical, the symmetry and optical characters of orthoclase being accounted for on the assumption that it is, so to speak, an ultra-microscopic microcline; that is a microcline in which the polysynthetic structure is so minute as to be incapable of resolution by our methods of examination. One and the same individual may show the characters of orthoclase in certain parts and those of microcline in other parts.

The alteration of microcline is similar to that of orthoclase. Under the influence of dynamic metamorphism it passes over into the mosaic-like aggregates already referred to.

Soda and Soda-lime Felspars.—Normal plagioclase felspars are present in almost all granites and occur not unfrequently in the trachytic rocks of similar composition. They belong for the most part to the oligoclase-andesine group. Albite is present in certain granites but appears to occur rather in drusy cavities, or intergrown with orthoclase, than as an independent rock-forming constituent. Labradorite has been found in the dark patches so common in many granitic rocks. In general character and mode of association the soda-lime felspars of the present group of rocks are similar to those of the intermediate group and require therefore no special description.

Quartz.—In the granitic rocks this mineral usually occurs in the form of grains or granular aggregates, less frequently in the form of ophitic plates with uniform extinction over considerable areas. Idiomorphic quartz is comparatively rare in the granitic rocks. Some rocks which have been termed granites (*e.g.*, rocks of Mull) exhibit the micro-pegmatitic structure in the greatest perfection. These may with propriety be termed granophyres notwithstanding the fact that porphyritic constituents are sometimes absent. In the trachytic rocks quartz occurs as one of the porphyritic constituents. It is then sometimes idiomorphic. The usual form is that of a double pyramid; the prismatic faces being absent or developed only to a very limited extent. As a general rule the angles are more or less rounded and sometimes the mineral occurs in the form of grains without any decided indications of crystalline form. Liquid inclusions are very common in the quartz of granites. They may lie in planes or may be irregularly distributed through the mineral. Details as to these inclusions have already been given and need not therefore be repeated. Liquid inclusions are generally absent in the trachytic rocks. Inclusions of the ground-mass are common and these not unfrequently take the form of negative crystals. The boundaries of the crystals and grains of quartz in the trachytic rocks are often

very irregular. Gulfs and fiords (fig. 2, Pl. XXXI.), as it were, penetrate into the substance of the mineral and are now occupied by the ground-mass of the rock. In studying thin sections it is often difficult to be certain whether a mass which is surrounded on all sides by quartz is really an inclusion or whether it is a section of an intruding arm cut so as not to show its connection with the ground-mass of the rock. The rounding of the angles of the quartz crystals in the trachytic rocks and the penetrations of the matrix are generally regarded as evidence of a corrosive action of the magma upon the earlier formed crystals. In rocks which contain two generations of quartz that of the second generation may occur in the form of grains (*e.g.*, micro-granite) or intergrown with orthoclase in micro-pegmatite (*e.g.*, granophyres). Quartz is one of the most stable minerals and accordingly we find that the quartz of granites and gneisses has contributed very largely to the formation of sedimentary rocks. Under the influence of dynamic metamorphism it breaks up into a mosaic. This is strikingly exhibited where gneisses have been formed by the deformation of granite. The granular character of the quartz is then easily recognizable with a lens. Under the microscope the grains of quartz which occur between the larger constituents are associated with grains of felspar of the same dimensions and the two minerals then form a granulitic aggregate.

Tridymite.—This form of silica is present in certain trachytes and liparites. It is often associated with opal and hyalite. It is best recognized in the drusy cavities, where it occurs in the form of flat hexagonal tables which do not as a rule measure more than 1 mm. across. The tables often overlap like the tiles on the roof of a house. As a constituent of the ground-mass tridymite occurs only in very minute plates. In this condition it may be recognized by the imbricate or tiled arrangement when a tolerably high magnifying power is employed. At ordinary temperatures tridymite behaves as a biaxial mineral and for some time was supposed to be triclinic. MERIAN [1] has shown that it becomes uniaxial on heating and it is accordingly now referred to the hexagonal system. Its double refraction is positive. Its specific gravity varies from 2·28 to 2·33 and is approximately the same as that of fused quartz.

Tridymite appears to be produced by the actions of vapours and solutions during the final stages of the consolidation of the rock in which it occurs. The researches of FRIEDEL and SARASIN prove that both tridymite and quartz may be produced in the wet way; the former at a higher temperature than the latter. Tridymite was recognized by Professor VON LASAULX [2] in the liparite of Tardree, Co. Antrim, and this remains at present the only recorded instance of the occurrence of this interesting mineral in the British Isles.

Mica.—The micas of the present group of rocks vary considerably in character and composition. They may be broadly separated into two groups; the dark coloured or black micas and the light coloured or white

(1) N.J., 1884, I., 193.

(2) Jour. Roy. Geol. Soc. (Ireland), New Series, Vol. IV., 1876, p. 227; and also T.M.M., Neue Folge, Vol. I., p. 410.

micas. The name biotite is often used by petrographical writers as almost synonymous with black mica, but it must be remembered that some magnesian micas are colourless and that some of the dark-coloured micas contain only small quantities of magnesia. Much work will have to be done before a satisfactory classification of the rock-forming micas is established. The black-micas of the present group of rocks occur for the most part in hexagonal plates. Less frequently as plates with irregular boundaries. As a rule they are nearly uniaxial. The optical axial plane lies in the plane of symmetry—that is parallel to two of the sides of the hexagon—and the double refraction is negative. The principal cleavage is approximately at right angles to the acute bisectrix so that these characters can be easily determined in a cleavage flake. The variety known as lepidomelane is characterized by a high percentage of ferric oxide. Dr. HEDDLE has proposed the term Haughtonite for a variety containing a small percentage of magnesia (1·5 to 14·77 p. c., mean 9·07 p. c.) and a large percentage of ferrous oxide (14·01 to 18·70, mean 17·22).[1] These varieties are probably the most common forms of black-mica in the acid igneous rocks. A very interesting form of black mica has been described by Professor SANDBERGER[2] under the name of proto-lithionit. It is stated by him to be a constituent of many granites, including those of Cornwall and the Mourne Mts. It is biaxial with a small optic axial angle. It melts easily before the blow-pipe and colours the flame a purplish-red. It is easily decomposed by warm hydrochloric acid. Specimens from different localities, when examined qualitatively, showed the presence of titanic acid, stannic acid, arsenic, copper, bismuth and uranium, with traces of tungstic and boracic acids. A specimen analysed by Dr. SHROEDER contained 3·386 p. c. of lithia, 8·514 of potash and less than 1 p. c. of magnesia. In colour it varies from black to brown. Thin flakes are brown by transmitted light. This mica differs from zinnwaldite in colour and mode of occurrence. The latter mineral is found only in veins and druses, the former occurs as a constituent of many granites. Protolithionite is of considerable importance as a possible source of the ores found in many mineral veins.

The following analyses will give some idea of the variability in the composition of the black-micas in British rocks.

		I.	II.	III.	IV.	V.	VI.
SiO_2	...	35·55	36·20	40·08	37·16	35·67	35·69
Al_2O_3	...	17·08	15·95	12·41	15·00	17·95	20·09
Fe_2O_3	...	23·70	27·19	13·47	7·69	7·19	2·23
FeO	...	3·55	0·64	2·67	17·35	18·06	14·01
MnO	...	1·95	1·50	·62	1·04	2·00	1·00
CaO	...	0·61	0·50	1·08	1·30	1·40	1·89
MgO	...	3·07	5·00	14·66	8·88	1·50	14·77
K_2O	...	9·45	8·65	7·57	8·18	9·27	7·38
Na_2O	...	0·35	0·16	2·15	1·60	3·81	·53
H_2O	...	4·30 (Ig.)	3·90 (Ig.)	5·29	2·12	3·20	2·46
		99·61	99·69	100·00	100·32	100·05	100·06

(1) Min. Mag., Vol. III., 1879, p. 81.

(2) Untersuchungen über Erzgänge. Würzburg. 1885, p. 167.

I [1] Lepidomelane from granite, Ballyellin, Co. Carlow, Leinster. (HAUGHTON).
II. Lepidomelane from granite, Ballygohen, Co. Donegal. (HAUGHTON).
III. Lepidomelane, vein in granite, Tongue, Sutherland. (HEDDLE).
IV. Haughtonite from granite vein, Roueval, Harris. (HEDDLE).
V. Haughtonite from vein in gneiss, Kinnaird Head. (HEDDLE).
VI. Haughtonite from granite, Ben Stack, Sutherland. (HEDDLE).

The black micas are easily affected by surface agencies when they become green and finally pass over into chlorite. The alteration often takes place along cleavage planes so that green and brown varieties frequently alternate with each other. In the volcanic rocks and in plutonic rocks with cataclastic structures the plates are frequently bent and crumpled. Inclusions of apatite, zircon and iron-ores are common; those of zircon are frequently surrounded by a deeply coloured zone in which the pleochroism is more marked than in the rest of the section.

The white micas belong for the most part to the muscovite group; lepidolite occurs in the granite of stanniferous districts but is more common in veins than in the main mass of the rock. Typical muscovite is present in certain granites but is absent from the corresponding volcanic rocks. It occurs as thin plates the outlines of which are more irregular than those of the black micas. The optic axial angle varies from 40° to 70°. The acute bisectrix is negative as in all micas.

Muscovite is colourless in thin sections. It possesses very strong double refraction ($\gamma - a$, 0.035) so that sections at right angles to the principal cleavage give the pinks and greens of the higher orders even in the ordinary rock sections. Analyses of muscovite invariably show a certain amount of water. Those which contain about 5 or 6 p. c. are sometimes termed margarodite.

White micas are extensively developed in connection with certain phases of dynamic metamorphism, especially when the deformation has been accompanied by shearing along more or less definite planes. The secondary mica may in these cases take the form of definite scales of muscovite or may occur in extremely fine grained aggregates giving a kind of crypto-crystalline reaction between crossed nicols. White micas are also frequently developed apart from all mechanical actions. In all cases they appear to be due to molecular changes in the felspar. Sericite is a term applied to a mica which occurs in minute irregular scales and scaly aggregates. It is identical with muscovite in composition.

The white micas, whether original or secondary, are very stable under the conditions which prevail at the surface of the earth and do not appear to undergo chemical change in the processes of denudation and

(1) I. and II. are quoted from Q.J.G.S., Vol. XV., p. 129; III., IV., V. and VI. from Trans. Roy. Soc., Edin. Vol. XXIX., p. 1.

deposition. They are accordingly very abundant in the sedimentary rocks.

	I.		II.		III.		IV.
SiO_2	44·71	...	44·64	...	43·47	...	46·23
Al_2O_3	31·13	...	30·18	...	31·42	...	33·03
Fe_2O_3	4·69	...	6·35	...	4·79	...	3·48
CaO	1·09	...	—	...	1·38	...	—
MgO	0·90	...	0·72	...	1·13	...	2·10
K_2O	9·91	...	12·40	...	10·71	...	8·87
Na_2O	1·27	...	—	...	1·44	...	1·45
Loss	6·22	...	5·32	...	5·43	...	4·12
	99·92		99·61		99·77		99·28

I. White mica from granite of Glendalough Valley, Co. Wicklow (HAUGHTON), axial angle 70° 4′.

II. White mica from granite of Mt. Leinster, Co. Carlow (HAUGHTON), axial angle 72° 18′.

III. White mica from Three Rock mountain, Co. Dublin (HAUGHTON), axial angle 5,° 8′. These micas are termed margarodite by HAUGHTON; muscovite by ROTH.

IV. White mica. Glenmalure, Co. Wicklow (Sullivan). Quoted from Rammelsberg's Mineralchemie, p. 516.

Pyroxene.—Monoclinic pyroxene occurs in certain granites, in many granophyres and in some liparites. The common variety in the granites is nearly colourless in thin section. It occurs as irregular grains or as crystals having more or less definite form. Twinning on the ordinary plan is very common. In the granophyres the augite is usually without form. It may be pale brown to colourless or green. The latter variety occurs in the Mull granophyres. Augite-bearing liparites are not known in the British Isles. Rhombic pyroxenes appear to be rare in the acid rocks. They occur, however, in certain pitchstones. They are usually found in association with monoclinic augite and the relations of the two minerals are the same as in the andesites.

Hornblende.—The hornblende of the acid rocks is similar to that of the intermediate rocks and requires no special description. Quartz-diorites shade into hornblende-granites in the most imperceptible manner.

Iron-ores.—These occur under the same conditions as in the intermediate rocks. They are, however, less abundant.

Apatite and *Zircon* occur almost constantly in granites. The latter mineral when present in the ferro-magnesian constituents is usually surrounded by a pleochroic border. It occurs in minute well-formed crystals or as grains. Glass inclusions containing two or more bubbles, sometimes more or less distorted, have been observed by CHRUSTSCHOFF in the granites of certain localities. As zircon probably belongs to the earliest period of crystal-development these glass inclusions are interesting as furnishing evidence that granite has resulted from the consolidation of a

homogeneous magma. The zircons of granites are generally less than the 1/100th of an inch in diameter. *Tourmaline* is an important constituent of many granites. It occurs in crystals, crystalline grains and irregular crystalline masses. The crystals belong to the hexagonal system and are hemimorphic. Cross sections show in convergent light the figure of a uniaxial mineral with negative double-refraction. Sometimes, however, the black cross breaks up into hyperbolæ as the stage is rotated in consequence of optic anomalies. A zonal structure is often seen when cross sections are examined in ordinary light. This is due to a variation in the colour of concentric layers. The colour of tourmaline in thin section is very variable. It may be yellow, brown, green or blue. Longitudinal sections are lath-shaped and strongly dichroic. The maximum absorption always takes place when the length of the section is at right angles to the short axis of the polarizer. This furnishes a ready means of distinguishing tourmaline from biotite. In tourmaline-bearing granites, such as those of Devon and Cornwall, the amount of tourmaline increases towards the margin of the principal masses and is often limited to the margins. It is, in part at any rate, a secondary product, developed in connection with boracic and fluoric acid exhalations. Where tourmaline occurs at the margins of granite masses it is also found in the adjacent sedimentary rocks. Tourmaline sometimes occurs in the form of acicular microlites which are often aggregated into radiating bundles. This is well seen in Luxullianite.

Topaz is so constantly present in greisen that it may be almost regarded as an essential constituent. It is colourless and often without form. Crystals of topaz have a short prismatic habit. The mineral is colourless in thin sections. The double-refraction is about the same as quartz. Cross sections show a positive bisectrix. The optic axial angle is large, so that the axes are not included within the field of view in the ordinary arrangement used with petrographical microscopes. There is a perfect cleavage parallel to the basal plane. The mineral is probably in all cases of secondary origin and developed in connection with fluoric acid exhalations. It occurs not only in greisen but also in granite. Granite shades into greisen by the disappearance of felspar; the topaz to a great extent taking its place.

Fluorite is a constituent of certain granites and especially of the variety known as trowlesworthite.

Cordierite and its pseudomorph *pinite* are found in some granites. Cordierite has been detected in the granite of Glencullen, Co. Dublin by Mr. Joly. [1] It shows the forms (100), (130), (110), (010) and (001). Pinite pseudomorphs after cordierite showing the forms (100), (110), (010) and (001) occur in the granite of Breage and the Land's End in Cornwall and in the quartz-felsite of Sydney Cove near Trewavas Head. *Garnet* is a constituent of certain granites and occurs also occasionally in the trachytic representatives of the acid group; as, for example, in the quartz-felsite of the Armboth dyke in the Lake District. Here it occurs in well-crystallized

(1) Sci. Proc. Roy. Dublin Soc., 1885, p. 48.

dodecahedra. *Orthite (allanite)* must also be mentioned as an accessory constituent of granitic rocks. *Andalusite* occurs as an accessory constituent of the Cheese-wring granite. It is often idiomorphic so far as the prismatic zone is concerned. The optical characters of this mineral will be described in the chapter on contact metamorphism.

Cassiterite.—This mineral occurs as an accessory constituent of granite in the neighbourhood of tin veins. The crystals are usually short and columnar. Cross sections are rectangular and extinguish when the cross wires bisect the angles formed by the meeting of the faces of the prism. They show in typical crystals the figure of a uniaxial mineral with positive double refraction when viewed in convergent light. Sometimes, however the black cross separates into hyperbolæ as the stage is rotated. Longitudinal sections are lath-shaped and give straight extinction. In thin section the mineral may be colourless, yellow, brown or reddish brown, very frequently an exquisite zonal structure may be observed. Refraction and double-refraction are both very strong.

Ground-mass of the trachytic rocks.—The trachytic representatives of the acid rocks are largely composed of a substance which cannot be resolved into distinct minerals by the unaided eye. Sometimes the rock wholly consists of such a substance; as a rule, however, it contains porphyritic crystals. Although not capable of resolving this substance the eye readily distinguishes two distinct modifications—the *glassy* and the *felsitic*. The glassy substance may have a vitreous or resinous lustre—the former characteristic of obsidian, the latter of pitchstone. When examined under the microscope the glass is usually seen to contain microlites, globulites, margarites and trichites. It is as a rule devoid of double-refraction. Nevertheless we sometimes find that the space surrounding the larger crystalline constituents gives a reaction with crossed nicols indicative of a state of strain. If the crystalline body be approximately circular in outline in the section the space surrounding it will show four light quadrants separated by the arms of a black cross. These arms will correspond in direction with the principal planes of the nicols. In other words the space surrounding the crystalline grain will behave as a spherulite yielding a black cross with this difference, that the exterior will be ill-defined. Perlitic structures are frequently present in the glassy rocks.

The felsitic substance differs from glass in being dull and stony in appearance. In chemical composition it agrees with many obsidians and pitchstones except that it contains little or no water. It consists essentially of silica, alumina and alkalies with small quantities of iron oxide. The ratio of alumina to alkalies is essentially the same as in the alkali-felspars, but the silica is in excess. The characters of this felsitic substance, or felsite as it may be termed, have been made the subject of researches by many observers and the most diverse opinions have been expressed as to their true significance. In pre-microscopic days petrographers possessed no methods by which the constituent parts of compact rocks could be recognized. The introduction of the microscope has given us a large amount of additional information, at the same time it has by no means

removed all difficulties. The examination of thin slices has enabled us to recognize that in many cases the felsitic matrix of the quartz-porphyries is a definite crystalline aggregate. VOGELSANG, as we have already seen, proposed the term granophyre for such rocks. ROSENBUSCH proved that the granophyres of VOGELSANG could be separated into two more or less distinct groups: (1) those in which the constituent minerals (quartz and felspar) occur as individual grains or crystals and (2) those in which the two minerals are inter-crystallized according to more or less definite laws. The former he proposed to call micro-granites, the latter granophyres. When, however, we have separated the micro-granites and the granophyres there yet remain many rocks in which the ground-mass is not composed of glass. What is the nature of this ground-mass? In many cases it gives under crossed nicols the vague kind of aggregate polarization which is generally known as crypto-crystalline. Now the term crypto-crystalline merely expresses the fact that the substance is composed either wholly or in part of double-refracting particles which are so small as not to be capable of definite recognition by the methods employed. Matter which appears crypto-crystalline when examined in thick sections and with low powers may often be resolved into a micro-crystalline aggregate or into an aggregate of double-refracting particles and a glassy base when examined in thinner sections and with higher powers. In dealing with this crypto-crystalline ground-mass we are brought face to face with difficulties of the same kind as those experienced by the older petrographers in dealing with the felsitic base. The introduction of the microscope has not removed the difficulties: it has merely pushed them further back. These considerations lead us therefore to the conclusion that the term crypto-crystalline includes different things and is useful merely for the purpose of expressing our ignorance as to the precise condition of the matter to which it is applied. It is an expression which is rendered necessary in consequence of imperfection in our methods of observation, and does not correspond with anything definite in the nature of things. It is a subjective and not an objective term, and one we must therefore use for the purpose of expressing our ignorance rather than for the purpose of concealing it.

Seeing that the term felsite is applied to matter which is incapable of resolution by examination with the naked eye or with a simple lens, it would seem perfectly natural that the term micro-felsite should be applied to the matter which is incapable of resolution under the microscope. This is approximately the sense in which it was used by ZIRKEL and VOGELSANG. ROSENBUSCH has, however, strongly argued against this use of the term. It is, however, somewhat difficult to understand precisely the view of the last-mentioned author. In the last edition (1887) of his work on the massive rocks, after referring to micro-crystalline, crypto-crystalline and glassy matter, he describes "a thoroughly isotropic substance, sometimes colourless, sometimes greyish, often, however, yellowish or brownish, which may be distinguished from a glass with devitrification products by the fact that it is not structureless, but is composed entirely, or almost entirely, of extremely

small fibres, scales or granules." This substance the author designates micro-felsite or micro-felsitic base. It occurs intimately interwoven with micro-crystalline and crypto-crystalline aggregates. He regards it as a definite chemical compound allied to felspar so far as the relations of the alkalies and alumina are concerned, but containing a higher percentage of silica. This substance, according to the author referred to, forms some of the spherulitic aggregations so characteristic of many felsites and liparites. When the fibres and scales are irregularly arranged the substance appears isotropic; when they assume parallelism, as in the case of the spherulitic aggregations, they exhibit weak double-refraction. From what has been stated above it appears that felsite is a macroscopic term used to include substances which present very different microscopic characters. Some felsites may be resolved into micro-crystalline aggregates of definitely recognizable minerals (quartz and felspar or mica), others appear crypto-crystalline, and others again are isotropic, but without that entire absence of structure which distinguishes a glass. In addition to the above we find felsites which break up under crossed nicols into aggregates of double refracting grains or patches, often of extreme irregularity, but of considerable size. The different varieties of felsite above referred to are intimately related to each other, and often coexist in the same rock. Flecks and specks of black, red and green substances are very common in felsitic matter VOGELSANG introduced the terms opacite, ferrite and viridite for these substances.

Spherulitic structures are very common in the trachytic rocks of acid composition. The larger structures are often complex[1] in character and will not be referred to at length in what follows.

VOGELSANG separated spherulitic (spherical) bodies into five groups.

I. *Cumulites.* These consist of more or less spherical aggregations of globulites without radial structure.

II. *Globospherites.* Aggregations of globulites or small cumulites with radial structure.

III. *Belonospherites.* These include aggregates with radial or concentric structures in which the elements are definitely recognizable crystals.

IV. *Felsospherites.* These include more or less spherical bodies not definitely recognizable as belonging to any of the other classes.

V. *Granospherites.* Spherical aggregates of definitely recognizable crystalline grains without radial or concentric structure.

The belonospherites of VOGELSANG are represented in the present group of rocks by more or less spherical aggregations of quartz and felspar—the pseudo-spherulites of ROSENBUSCH. The outlines of these aggregates are generally ill-defined. They are well-developed in certain portions of the Armboth dyke and in the granophyre of Carrock Fell. The felsospherites of VOGELSANG include many spherical bodies which present very different appearances under the microscope. The relations of these different bodies to

(1) See DELESSE, Recherches sur les roches globuleuses. Soc. Geol. 2nd. Se. T. IV. Mem. No. 5.

each other and to the belonospherites (pseudo-spherulites) and granospherites is by no means well defined. In the glassy rocks we frequently find more or less spherical patches of crypto-crystalline felsite, or isotropic micro-felsite without radial or concentric structure. These are sometimes aggregated together so as to form bands. In spherulites of this type the fibres instead of radiating from one point frequently radiate from two or more points so as to produce a complex structure. Again, it frequently happens that the spherulites have been developed side by side, in which case the spherical form of the individuals is more or less destroyed by mutual interference. When the fibres do not radiate from a point, but from a line of greater or less length, we have the structure for which ZIRKEL proposed the term *axiolite*. The lithoidal or stony bands in many laminated rhyolites are made up of spherulites and axiolites which have often suffered mechanical deformation by movements in the magma after they have been developed, and before the final consolidation of the rock.(1)

By an increase in the amount of this felsitic matter the glassy rock passes into a true felsite. Sometimes a more or less marked fibrous structure occurs in this felsite. When this is the case and when the fibres radiate from a centre the spherulite gives a black cross in polarized light with crossed nicols, and the character of the double refraction is positive, that is the minor axis of depolarization at any point is coincident with the radius of the spherulite. The spherulites of the Lea Rock may be quoted as examples of this type. They usually occur as more or less independent bodies in a glassy matrix and are generally more deeply coloured than the rest of the rock. Thus the spherulites and felsitic bands in the Lea Rock are stained a deep red by specks and flakes of ferrite. When examined with a high power the fibrous structure appears to be due to the arrangement of the disseminated dusty particles. Distinct crystalline fibres cannot be made out. In many felsites we find spherulites of a totally different character from those above described. They are extremely minute, well-defined at their margins and give a sharp, black cross. In ordinary light they show a radial structure, and are frequently more transparent than the matrix in which they lie. The character of the double refraction is negative; in other words the major axis of depolarization is coincident with the radius of the spherulite at any point. Good examples of this kind of spherulite occur in the "spotted" felsite of St. David's, and in many (not all) of the spherulitic felsites of Arran. Spherulites of this kind sometimes form the main mass of the felsite in which they occur; at other times they are aggregated in bands and patches. They are similar in appearance and optical characters to the spherulites in hyalite.

The conditions under which the double refraction of certain felsitic rocks has been produced have been investigated by Messrs. RUTLEY and ALLPORT who have proved that in many cases it is undoubtedly a secondary phenomenon due to the devitrification of a glass.

Glassy rocks of pre-carboniferous age are unknown, but their devitrified

(1) SCROPE. Geology of the Ponza Isles. Trans. Geol. Soc., Vol. II., 2nd series.

representatives are common. In the micro-granites and granophyres the double-refraction, due to the fact that the ground-mass is composed of the definite minerals, quartz and felspar, is probably in all cases original. In the felsophyres it may be original or secondary. At the present time we unfortunately possess no criterion by which we can decide as to its true character in the absence of structures which certainly indicate the original presence of glass. Perlitic felsites are, however, very common, and in all such cases we may safely infer that the original rock was a perlitic obsidian or pitchstone. In the majority of cases the perlitic felsites are crypto-crystalline. The double-refracting portions are so small and overlap so frequently as to make it impossible to state anything definite with regard to them, even in the thinnest sections. It sometimes happens, however, that the felsite appears to be micro-crystalline. In this case the boundaries of the individual grains are never so well-defined as in the micro-granites, and a differentiation of the grains into the two minerals quartz and felspar is impossible. Another and a somewhat special type of devitrification is the spherulitic. Mr. RUTLEY has shown that a perlitic felsite from the Long Sleddale Valley, in the Lake District, is largely composed of minute spherulites giving a well-defined black cross and bearing such a relation to the perlitic cracks as to leave no doubt whatever that they are of secondary origin. These spherulites are positive. What may be termed the micro-crystalline in contradistinction to the common or crypto-crystalline type of devitrification occurs also in the same rock (see Fig. 2, Plate XXXVIII.).

DESCRIPTION OF THE ROCKS.

Granites occur as a rule in large intrusive masses. They are distinctly and often coarsely crystalline in the central portions of the mass, but they may become finely crystalline at the margins and in the apophyses. Granites may in fact be seen to pass gradually into micro-granites, granophyres and felsophyres. They vary considerably in colour and composition, but there is generally a close resemblance between the granites of one locality and of one geological epoch. A comparative study of British granites with a view to ascertain the relative importance of the different points of resemblance and difference has not as yet been made. In reviewing what is known as to the granites of different localities some information will be given on these points, but much work will have to be done before our knowledge becomes at all satisfactory.

A very interesting feature of granites is the frequent occurrence in them of nodules and patches which differ in composition from the main mass of the rock. We are indebted to Mr. J. A. PHILLIPS[1] for most valuable information as to the nature of these patches. Sometimes they undoubtedly consist of fragments of foreign rocks, more or less altered and impregnated with granitic materials; at other times they are composed of the same minerals as the granite associated in different proportions. In

(1) Q.J.G.S., Vol. XXXVI. (1880), p. 1.

the latter case the patches are generally richer in the more basic constituents, such as plagioclase and biotite—they may be described in many cases as patches of diorite in granite. Thus, these inclusions bear the same relation to granite that the nodules of peridotite, so common in many Continental basalts, do to the rock in which they occur. It seems impossible to avoid the conclusion that somehow or other these patches are the result of differentiation accompanying the crystallization of the original magma. As this point is one of general interest we will quote Mr. PHILLIPS' analyses of the granites and the more basic inclusions which occur in them before proceeding to describe the rocks of special localities.

	I.	Ia.	II.	IIa.
SiO_2 ...	69·64	65·01	73·70	64·39
Al_2O_3 ...	17·35	17·37	14·44	15·99
Fe_2O_3 ...	1·04	4·95	·43	1·47
FeO ...	1·97	1·86	1·49	5·98
MnO ...	tr.	tr.	tr.	tr.
CaO ...	1·40	2·11	1·08	2·57
MgO ...	·21	1·34	tr.	1·67
K_2O ...	4·08	1·82	4·43	2·46
Li_2O ...	tr.	tr.	—	—
Na_2O ...	3·51	4·14	4·21	4·96
P_2O_5 ...	tr.	tr.	tr.	tr.
H_2O ...	·72	1·43	·61	·95
	99·92	100·03	100·39	100·44
Sp. Gr.	2·72	2·73	2·69	2·73

I. Grey granite from Gready in the parish of Luxulyan, Cornwall. This granite contains two micas and an occasional crystal of tourmaline. Garnet is sometimes present.

Ia. Dark ovoid patch in the above, containing more biotite and plagioclase than the main mass of the rock.

II. Pink granite of Peterhead, near Aberdeen. Composed of quartz, orthoclase, plagioclase and black mica with a little apatite and titanite.

IIa. Dark coloured and fine-grained patch in the above. Contains more plagioclase and dark mica than the main mass of the rock.

It will be seen from the above analyses that the basic patches are poorer in silica, richer in lime, iron and magnesia, and poorer in alkalies than the rocks in which they occur. Moreover the relations of the alkalies are different in the rocks and in the inclusions; in the former potash predominates, in the latter soda. As intimately connected with the phenomena of inclusions we may mention the fact that in certain localities granitic and dioritic rocks vein each other in the most intricate manner; not as if the one rock had been intruded into the other but rather as if the two rocks were the result of differentiation in a magma during solidification. If we suppose movement to take place in a magma after the differentiation of dioritic masses and when the mother liquor possesses the composition of granite we can readily understand how dark patches and streaks of dioritic rock may occur in granite. According to this view the want of homogeneity

in a plutonic mass would not be the result of the imperfect mixing of the original materials; but would be due to differentiation taking place in a magma which may have been perfectly uniform in composition. In connection with this subject we may also refer to the development of foliation in plutonic rocks by differential movement accompanying intrusion. The foliation may consist merely in a parallel arrangement of certain constituents of the granite, as for example the micas and the tabular felspar crystals; or it may consist of a parallel banding. In the latter case it is of course necessary that the magma should not have been homogeneous at the time of intrusion, as the bands vary in mineralogical composition. An admirable illustration of the phenomena referred to may be seen in the Langesundsfjord (Norway) [1] near the margin of a mass of undoubtedly intrusive augite-syenite. Bands of a lighter and darker colour alternate with each other so that the parallel structure is often as perfect as in many crystalline schists.

Granites may be either porphyritic or non-porphyritic. The porphyritic constituent is orthoclase. It occurs as a rule in more or less tabular crystals in consequence of the conspicuous development of the clinopinacoid. This is the case in the well-known Shap granite and in many of the Cornish granites. In the building of granite zircon and apatite belong undoubtedly to the earliest period of crystal development. They occur as inclusions in the other constituents. Sphene also when present belongs as a rule to the same period. The ferro-magnesian minerals follow next and last of all the felspar and quartz. The relations of the felspar and quartz are somewhat complicated and no definite rule can be laid down to express their order of formation. Plagioclase in almost if not in all cases precedes quartz and generally, but not invariably, precedes orthoclase. In the porphyritic granites orthoclase belongs to two periods. The porphyritic orthoclase is idiomorphic; the orthoclase of the ground-mass is generally allotriomorphic. It is commonly stated that the quartz of granites forms the matrix in which the other constituents lie embedded; that it was the last mineral to form and that it accordingly takes its shape from the disposition of adjacent crystals. This is by no means so universally true as is commonly supposed. We frequently find that the quartz and the orthoclase have mutually interfered with each other so that neither mineral shows good form; sometimes they have intercrystallized so as to form micro-pegmatite as in some of the granites of Mull (granophyres) and the Mourne Mountains. In the granites with two micas (muscovite-biotite granites) the quartz occasionally shows more or less definite form and is idiomorphic with respect to the orthoclase. It thus appears that in some cases the quartz has succeeded the orthoclase; in other cases it has preceded the orthoclase; in others the two minerals have crystallized simultaneously. Idiomorphic quartz is rarely if ever found in the biotite- and hornblende-granites. Microcline bears very much the same relation as orthoclase to the other constituents of the rock. Tourmaline, topaz and

(1) Brögger, Die silurischen Etagen 2 und 3, p. 327.

fluor are probably in many cases secondary minerals developed in connection with exhalations of boracic and fluoric acids. White mica is often developed in consequence of the alteration of felspar. This mica must be carefully distinguished from the white mica which occurs as an original constituent of many granites. Epidote, chlorite and other minerals frequently arise in connection with secondary processes. We will now refer to the granites of special localities.

West of England.—Details as to the mode of occurrence of these granites will be found in the Geological Report on Cornwall, Devon and W. Somerset by De la Beche. The petrographical characters of the rocks, so far as these could be ascertained by macroscopic examination, are also given in the Report and in older communications by Mr. Majendie, Dr. Boaze,(1) Mr. Carne and others. The microscopic characters of some of the granites and of the altered rocks near the margin of the granite-masses have been described by Allport,(2) Bonney,(3) Phillips,(4) Rutley,(5) and Worth.(6)

On the mainland of Devon and Cornwall there are five principal and many smaller exposures of granite. The five principal masses may be referred to as those of Dartmoor, Brown Willy, Hensborough or St. Austel, Carn Menelez and the Land's End. Notwithstanding many local variations there is a general uniformity in the character of the rock from the different localities. It consists essentially of quartz, orthoclase, plagioclase, dark mica and white or light coloured mica. Porphyritic crystals of white orthoclase are sometimes present and sometimes absent. They sometimes attain very large dimensions measuring two or three inches across. The prevailing colour is grey. Red tints are rare. A fine red granite occurs, however, at Trowlesworthy and veins of red granite may be observed, according to Mr. Worth, near Shaugh, at Hanger Down and in the upper valley of the Tavy. The grain is coarse in the central parts, but becomes finer at the margins and in the apophyses. The dark mica sometimes disappears and under these circumstances the rock becomes a white muscovite-granite or aplite. Under the microscope zircon and apatite may be detected in almost every section. Where zircon occurs as inclusions in the micas it is surrounded by a coloured border; in the black mica this border is frequently so dark as to be opaque, in the light-coloured mica it is faint but generally distinct. In the lath-shaped sections it is only seen when viewed with rays vibrating parallel to the cleavages. The apatite is not surrounded by a similar border. The principal constituents of the granite do not as a rule (with the exception

(1) Trans. Roy. Soc. Corn., Vol. IV. (1832), p. 165.

(2) On the metamorphic rocks surrounding the Land's End Mass of Granite. Q.J.G.S., Vol. XXXII. (1876), p. 407.

(3) On the microscopical structure of Luxullianite. M.M. (1878), pp. 5-9.

(4) On the rocks of the mining districts of Cornwall. Q.J.G.S., Vol. XXXI. (1875), pp. 319-344. On concretionary patches and fragments of other rocks contained in Granite. Q.J.G.S., Vol. XXXVI. (1880), pp. 1-21.

(5) The Eruptive rocks of Brent Tor and its neighbourhood. Mem. Geol. Sur., 1878.

(6) The Rocks of Plymouth. Trans. Plymouth Inst. 1886.

of the porphyritic felspars when these are present) show good form. The two micas are often seen to be intergrown in parallel lamellæ. The striated felspar appears to be generally idiomorphic with respect to quartz and orthoclase; sometimes, however, it occurs as patches in the orthoclase. The latter mineral is generally devoid of optical uniformity. Different portions of one and the same individual extinguish in slightly different azimuths. Sometimes the different portions give a striped character to the appearance of the section under crossed nicols. Typical microcline appears to be rare, if not altogether absent.

Quartz generally occurs in the form of grains and granulitic aggregates; occasionally it shows traces of crystalline form and when this is the case it is seen to be idiomorphic with respect to the orthoclase. Irregular inclusions containing more or less liquid, and sometimes also a cubic crystal, are almost always present in the quartz. Liquid carbonic acid is recorded by ROSENBUSCH as occurring in the quartz of a granite from Penzance. The following analyses by Mr. PHILLIPS taken in connection with the one already quoted will give an idea of the composition of the normal granite of the West of England.

	I.	II.	III.
SiO_2 ...	74·69	74·54	70·65
Al_2O ...	16·21	14·86	16·16
Fe_2O ...	tr.	2·53	1·53
FeO ...	1·16	·23	·52
MnO ...	·58	tr.	tr.
CaO ...	·28	·29	·55
MgO ...	·48	tr.	tr.
K_2O ...	3·64	3·73	8·66
Na_2O ...	1·18	3·49	·54
Li_2O ..	10	tr	—
H_2O ...	1·23	·87	1·22
	99·55	100·54	99·83
Sp. Gr. ...	2·64	2·66	2·62

I. Carn Brea Hill, Redruth. II. Botallack. III. Chywoon Morvah.

So far we have been referring to what may be termed the normal type of the West of England granite. We have now to refer to more or less exceptional varieties. Of all the accessory minerals tourmaline is undoubtedly the most important. It occurs as fair-sized crystals, grains, irregular masses or acicular microlites. The microlites often occur in radiating bundles which penetrate the individuals of quartz. The crystals are of the usual nine-sided form; sometimes, however, they are six-sided. The amount of tourmaline increases towards the margins of the granitic masses. The increase in the amount of tourmaline is accompanied by the disappearance of mica and finally of felspar; the ultimate result being a rock composed of tourmaline and quartz (schorl-rock). Good examples of schorl-rock occur at Roche, on the boundary of the Hensborough mass, and on the north side of the Land's End mass near Zennor. The central portions of the granite-masses are sometimes entirely free from tourmaline.

The tourmaline is sometimes found to be scattered through the rock as a normal constituent; at other times it is aggregated in nests and veins. De la Beche mentions the occurrence of a curious concretionary arrangement in the case of a block found near Blatchford, Cornwood. In the centre was an ellipsoidal cavity measuring about one foot in its longest diameter. This was not quite filled with long crystals of tourmaline crossing each other in different directions but with a general tendency towards the centre. Surrounding this in a concentric manner was a zone of tourmaline and quartz, the latter mineral predominating, and outside this again was a zone of dark schorl-rock. This concretionary ellipsoidal patch, measuring two feet in its largest diameter, occurred in a light flesh-coloured granite. A remarkable rock composed of tourmaline and quartz occurs at the Single Rose Clay Works. It contains large pseudomorphs of granular quartz after felspar in a black ground-mass of schorl-rock. The rock itself may be regarded as a pseudomorph after a porphyritic granite. It is somewhat remarkable that the pseudomorphs after the large porphyritic felspars should be almost entirely free from tourmaline. The well-known luxullianite [1] bears some relation to the above. It consists of porphyritic crystals of pink orthoclase in Carlsbad twins embedded in a black matrix of schorl-rock If the large felspars in this rock were replaced by granular quartz the resulting product would bear the closest resemblance macroscopically to the rock of Single Rose. The tourmaline of luxullianite is present in two forms (1) as brown crystals and grains and (2) as radiating acicular crystals. The acicular crystals lie embedded in quartz. The orthoclase is turbid in thin section. A consideration of the distribution of tourmaline in the granites of Cornwall points to the conclusion that it must be regarded rather as a secondary than an original product. Exhalations of boracic, fluoric and other acids accompanying, it may be, the final stages of igneous activity have evidently exerted a profound mineralizing effect not only on the granites but also on the surrounding rocks. [2] Nevertheless it must be admitted that in many cases the tourmaline plays the rôle of a normal constituent; in other words its relation to the other constituents as seen in thin section is difficult to account for on the theory that it is of secondary origin.

The passage of normal granite into greisen is in some respects analogous to the passage of the same rock into a compound of tourmaline and quartz. Felspar disappears and topaz is generally developed. Excellent illustrations of this passage may be seen on the south-east shore of St. Michael's Mount. The principal joint planes in the granite run approximately E. and W. These carry quartz, cassiterite, topaz, wolfram and apatite. They are bordered on either side by a band of greisen, from six inches to a foot in width, which shades off insensibly into the granite. The greisen is a dark grey rock composed of quartz, white mica, topaz and a little brown tourmaline.

(1) Bonney, M.M., 1877, pp. 215-222.

(2) See Daubrée, Géologie Expérimentale, p. 61.

A very remarkable variety of granite has been described by Professor BONNEY [1] under the name of Trowlesworthite. It appears to be a local variety of the red granite of Trowlesworthy and is composed of red felspar, acicular tourmaline, purple fluor spar, and an occasional grain of quartz. The fluor spar forms about one-fifth or one-sixth of the entire mass and appears to occupy the place of the quartz of the normal granite. The felspar is much decomposed and occasionally contains patches of tourmaline and quartz. Where tourmaline has been developed in the felspar of the granites now under consideration it is almost, if not always, accompanied by quartz. In addition to the accessory constituents already mentioned we find also in certain localities cassiterite, pinite and andalusite. Mr. PHILLIPS mentions the occurrence of garnet and beryl. Cassiterite occurs in the granite of Shaugh in Devon according to Mr. WORTH. Pinite in the form of cordierite is found in the granite of the Land's End. Andalusite is present in the rock which is quarried near the Cheesewring. It appears to be a normal constituent of the granite.

A remarkable variety of granite occurs at Meldon near Okehampton. It is almost a pure white, somewhat resembling statuary marble in appearance and is composed essentially of quartz, felspar (largely plagioclase), white mica and topaz. [2] Black mica is absent. The rock is therefore a muscovite-granite. It contains also green tourmaline.

The granite of Dartmoor is certainly of later date than the Culm-measures and earlier than the Trias. The other granites above referred to, including also the granite of the Scilly Isles, are presumably of the same age.

Granite occurs in the Lizard peninsula as veins in serpentine, gabbro and a dioritic rock. It is, however, very different in character from the granites already referred to. At Kynance it occurs as veins or dykes in the serpentine; at Pen Voose it may be seen to vein a dioritic rock in the most intricate manner; in a cove north of Pen Voose it occurs in gabbro. At Kennack Cove it may be also seen veining diorite. The granite of the Lizard, like the gabbro and serpentine, has been profoundly modified locally by dynamic metamorphism, and passes over into gneissose and schistose rocks. The least modified granite is of medium or fine grain and is composed of quartz, felspar and dark mica. It is generally pink in colour and often becomes a

(1) Trans. Roy. Geol. Soc., Cornwall. 1884. Vol. X., Part 6, p. 180.

(2) The topaz in this rock rarely shows good form in thin sections. It is colourless and possesses the characteristic refraction and double-refraction. To remove all doubt as to the identification of the mineral the powder of the rock which passed through a sieve with fifty meshes to the inch and was retained by one having eighty meshes was placed in a solution of boro-tungstate of cadmium having a specific gravity of 3·2. The mineral in question fell down whilst the other constituents floated. Cleavage flakes were easily picked out from the powder and these gave in convergent light the interference figure of topaz—they were seen to be at right angles to a positive bisectrix and the optic axial angle was as near as could be judged that of topaz. Grains of the powder pressed into lead could be made to scratch glass. Mixed with microcomic salt and fused in an open tube acid vapours were given off which etched glass. There can be no doubt therefore that the mineral is topaz although it occurs in allotriomorphic grains and frequently does not show good cleavage in the thin sections.

bright red by alteration. In the deformed rock-masses the original micro-structure of a granite has been more or less replaced by that of a gneiss or schist. A parallel structure has been developed. This may or may not have been accompanied by the development of white mica. When at all pronounced it is invariably accompanied by the development of micro-crystalline or granulitic aggregates of quartz and felspar and these aggregates by their distribution in the rock, and especially by their relation to the larger grains of quartz and felspar, serve to define the parallel structure. Sometimes the aggregates are so fine as to be incapable of resolution into distinct grains in which case they must be described as crypto-crystalline. They occur as lenticular stripes and bands of greater or less width which wind in and out amongst the larger constituents and produce what may be aptly termed a micro-flaser structure. A good example of a gneiss of this type occurs above Kynance at the point where the road begins to descend. It forms a band in the serpentine and is exposed in the floor of the road. Under the microscope it is seen to consist of large irregular felspar-grains which are partly striated and partly not. These grains give undulose extinction and are sometimes broken; the parts not having been far removed from each other. They are arranged with their longest diameters parallel with the foliation and are sometimes traversed by cracks at right angles to the foliation. The ground-mass is a micro- or crypto-crystalline aggregate mainly composed, it may be presumed, of quartz and felspar. Owing to a variation in the size of the grains of different portions of this aggregate and to the existence of a certain amount of uniformity in the orientation of the grains in certain patches a marked parallel structure is apparent under crossed nicols. Narrow lenticular stripes and patches are recognizable and these sweep round the larger constituents in the graceful curves suggestive of fluxion structure. There is a little biotite recognizable and there are dark wavy lines without definite character which may represent the mechanically disintegrated remnants of this mineral.

A light-coloured gneissose rock occurs above the shore near Porthalla. It has been described by Prof. BONNEY.[1] This rock is more or less fissile, the planes of schistosity being coated with a white mica. In micro-structure it bears a close relation to the rock just described except that white mica has been extensively developed along certain planes. This mica occurs partly in the condition of definite but ragged crystalline scales, and partly in a fine-grained aggregate. Colonel MACMAHON has proposed that mica in the latter condition should be termed crypto-crystalline.[2] The larger crystalline constituents in this rock are similar to those of the rock from Kynance. They lie in a micro-crystalline

(1) Q.J.G.S., Vol. XXXIX., p. 14.

(2) Microscopic structure of some Dalhousie rocks. Records of the Geol. Survey of India. Vol. XVI., Pt. 3 (1883), p. 131.

mosaic of water-clear grains (see Fig. 1, Plate XLII.). The micro-flaser or fluxion structure is as perfect in this rock as in the rock from Kynance; it is indeed somewhat better defined under crossed nicols in consequence of the distribution of white mica in wavy planes. Tourmaline occurs sparingly. Prof. BONNEY mentions the occurrence of garnet. This rock bears the closest possible resemblance to some specimens of the gneissose granite of Dalhousie. Colonel MACMAHON regards the micro-fluxion structure in these rocks as original and connected with the intrusion of the granite. The present writer is inclined to regard the corresponding structure in the Porthalla rock as the consequence of the regional metamorphism which has affected the district and produced allied structures in the gabbros and serpentines.

Wales.—In north Pembrokeshire there occurs, in the neighbourhood of St. David's, a mass of granitic rock which has given rise to a good deal of discussion. It was mapped as syenite, intrusive in Cambrian rocks, by the geological surveyors. Dr. HICKS considered it to be a metamorphic rock of pre-Cambrian age belonging to his Dimetian system. Dr. GEIKIE maintains that it is an intrusive granite of Cambrian or post-Cambrian age. Professor BLAKE holds that it is a granite, but of pre-Cambrian age. The petrographical characters of the rock in question have been described by Messrs. DAVIES [1] and TAWNEY, [2] Drs. BONNEY [3] and GEIKIE,[4] and Professor BLAKE.[5] In its typical development it is a massive, granular holo-crystalline rock composed of quartz, orthoclase, plagioclase and a green chloritic mineral of somewhat indefinite character. The felspars are turbid and often contain minute crystalline flakes of white mica (secondary). The quartz occurs as a rule in grains but sometimes shows traces of crystalline outline. It abounds in fluid inclusions which are often arranged in planes running roughly parallel to each other and passing from one grain to another without change of direction. Sometimes also fine cracks, occupied by a micro-crystalline mosaic, traverse the slide for a greater or less distance. These phenomena point to the conclusion that the rock has been more or less affected by dynamic metamorphism. The relation of the quartz to the felspar in this rock is interesting. Sometimes the two minerals occur in irregular grains, at other times the felspar plays the rôle of matrix to the quartz, at others the two minerals are inter-crystallized so as to form micro-pegmatite. Segregation veins occur in the main mass and in these the micro-pegmatitic structure is generally well developed according to Dr. GEIKIE. The viridite undoubtedly represents one or more of the ferro-magnesian constituents, biotite, hornblende or augite

(1) Q.J.G.S., Vol. XXXIII. (1877), p. 231 (foot note).

(2) Proc. Bristol Nat. Soc., Vol. II., part 2, p. 112.

(3) Q.J.G.S., Vol. XXXIV. (1878), p. 155.

(4) Q.J.G.S., Vol. XXXIX. (1883), p. 313.

(5) Q.J.G.S., Vol. XL. (1884), p. 302.

In the tendency to a micro-pegmatitic structure this rock differs from the granites of the West of England, the south-east of Ireland, and the central and eastern parts of Scotland; but resembles the granites (granophyres) of Mull and the Mourne Mountains. Mr. DAVIES was struck with the resemblance of some portions of the St. David's rock to the Mull granophyres. It is worthy of note that in these granophyres augite is frequently the only ferro-magnesian constituent.

The rock above described is associated with felsites in which a spherulitic or pseudo-spherulitic structure is well developed. These will be referred to later on. They are supposed by Dr. GEIKIE to represent the marginal portions and the apophyses of the granitic rock. Dr. HICKS, however, considers them to be of independent origin.

In the ridge of crystalline rocks running more or less continuously from Langwm to Talbenny, south of Haverfordwest, granite occurs in association with quartz-diorite; the granite veins the diorite. In the quarry at Targate both rocks are massive. Near Talbenny they become gneissose, as has been pointed out by Dr. HICKS and Mr. DAVIES.[1]

Granitic rocks are exposed in many localities in North Wales. At Moel-tan-y-grisiau near Ffestiniog there occurs a rock, mapped as syenite, which bears the closest resemblance both macroscopically and microscopically to the rock of Bryn-y-garn near St. David's. It is, however, decidedly fresher. The quartz is tolerably free from inclusions. The felspar is turbid but frequently shows sufficient individual action to enable one to recognize its character. It is partly striated after the fashion of normal plagioclase, partly unstriated and partly cross-hatched in such a way as to suggest microcline. The felspar and quartz are related to each other as in the St. David's rock. The viridite of the St. David's rock is represented by brown or green mica which occurs in aggregates, not in individual crystals. Hornblende occurs sparingly in ragged grains. Grains of zircon are present as inclusions in the other constituents and there are a few grains of iron-ore.

The rock of Twt Hill near Caernarvon, for which Professor BONNEY[2] proposed the term granitoidite, is allied to the rock above described. The relation of the quartz to the felspar is similar and there is the same tendency to a micro-pegmatitic or granophyric structure. Ferro-magnesian constituents are, however, almost entirely absent. Similar rocks occur at Tymawr and Rhos Hirwain in the Lleyn peninsula and at Ty Croes, Llanfaelog and other localities in Anglesea.[3]

A rock of this type from Meillionydd House, about three miles N.E.

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(1) Q.J.G.S., Vol. XL. (1884), p. 507. The district in which these rocks occur has been profoundly affected by post-carboniferous earth-movements. An interesting question arises as to whether the gneissose structures in the igneous rocks may not be the result of these movements.

(2) Q.J.G.S., Vol. XXXV. (1879), p. 321.

(3) See HICKS & BONNEY, Q.J.G.S., Vol. XXXV.; also Vol. XL. (1884), p. 200; TAWNEY, G.M., Decade II., Vol. X. (1883), p. 65.

of Aberdaron in the Lleyn peninsula is fairly rich in a strongly pleochroic mica. Crystals and grains of zircon are common and when they occur in the mica are surrounded by a strongly pleochroic border. Apatite is also present. The rock from Llanfaelog, Anglesea, exhibits in certain localities most interesting crush-phenomena, as Professor BONNEY has pointed out. These phenomena are similar in all essential respects to those exhibited by the Porthalla "gneiss;" there is the same white mica occurring partly in ragged scales and partly in the crypto-crystalline condition, there is the same micro-crystalline mosaic of colourless grains, and the same evidence of bending and fracture in the larger constituents.

It will be seen from what has been stated above that the granitic rocks of Wales, so far as they have been examined, belong to one type and that this type is very distinct from that of the granites of the West of England. It is characterized mainly by the relation of the quartz and the felspar; the felspar occasionally assuming the rôle of ground-mass and occasionally occurring as a constituent of micro-pegmatite. There is no original white mica and black mica is comparatively rare. In some cases the rock is almost entirely composed of quartz and felspar. In many cases the quartz is rendered turbid by numerous inclusions arranged in planes which often traverse several grains and exhibit a rude parallelism in their mode of arrangement. This is probably a secondary phenomenon due to, or connected with, dynamic metamorphism. In some cases, as at Llanfaelog, the rocks have been foliated and white mica has been developed along wavy planes. This also is in all probability a phenomenon of dynamic metamorphism. The rocks in question resemble granites and granophyres of undoubtedly igneous origin. With regard to their age there is some difference of opinion. Pebbles of the rocks occur, however, in conglomerates which certainly belong to the early part of the Ordovician and probably to the Cambrian period.[1]

Midland Counties.—Rocks of the type just described occur at Ercal Hill and on the W. and S. W. slopes of Primrose Hill.[2] The Ercal rock contains only very small traces of any ferro-magnesian constituent. It is essentially composed of quartz and felspar. These two minerals are related to each other as in the St. David's, Twt Hill and Tan-y-grisiau rocks. The quartz is not unfrequently seen to be distinctly idiomorphic with respect to the felspar. Some portions of the mass exhibit the finest possible illustrations of micro-pegmatitic structures. Certain sections of this rock and of a corresponding rock from Twt Hill in Caernarvonshire bear a very close resemblance to specimens of a "granophyre" from Brinzio near Varese.[3]

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(1) Q.J.G.S., Vol. XL. (1884), p. 206.

(2) See Drs. CALLAWAY and BONNEY, Vol. XXXV. (1879), p. 643.

(3) HARADA, N.J., Beilage Band II., 1883, p. 1.

Granitic rocks occur in the Malvern Hills in association with diorites. They have not, however, as yet been described in detail.

	I.	II.	III.	IV.
SiO_2 ...	76·8	74·6	75·2	75·2
TiO^2 ...	·4	none	·2	·2
Al_2O_3 ...	13·4	14·2	13·0	13·7
Fe_2O_3 ...	·6	1·2	·7	1·3
FeO ...	·1	tr.	·4	·6
CaO ...	tr.	·4	·4	·4
MgO ...	tr.	·3	·3	·3
K_2O ...	6·2	4·9	7·1	4·0
Na_2O ...	2·2	3·7	1·9	2·6
H_2O ...	·5	·8	·7	·9
	100·2	100·1	99·9	99·2
Sp. Gr.	2·575	2·601	2·594	2·604

I. Red granitic rock. Ercal Hill.
II. Quartz-felspar rock. North Hill, Malvern.
III. Quartz-felspar rock. Malvern. Coarse granitic texture.
IV. Quartz-felspar rock. Malvern. Fine-grained.

These analyses are all by Mr. PLAYER.(1)

The granites of Leicestershire have been described by Messrs. HILL and BONNEY.(2) The dominant rock in the great quarry at Mount Sorrel is a pink biotite-granite (granitite). The striated felspar in this rock is frequently zoned. The quartz is often idiomorphic with respect to the unstriated felspar. Epidote, pyrite, barium sulphate, copper carbonate and molybdenite occur associated with the granite in nests and veins. Contemporaneous veins of pink felsite have been observed in the Mount Sorrel mass. Dr. SORBY (3) has described the microscopic structure of the Mount Sorrel rock and of the glass which resulted from the cooling of portions artificially fused. Mr. MARSHALL who conducted the experiments succeeded in melting in some cases over a ton of the rock. The glass formed by rapid cooling showed under the microscope radial concretions of black oxide of iron surrounded by clear spaces in a dark glass. Other portions showed a fern-like or dendritic arrangement of the oxide. The more slowly-cooled masses showed glassy and stony parts. In fusing the masses it was observed that the ferro-magnesian constituents melted first and that the quartz and felspar tended to rise to a certain extent. This last observation is of great interest inasmuch as it shows that a cooling mass of molten rock may become differentiated into basic and acid portions.

Hornblende does not play an important part in the Mount Sorrel granite but it occurs more abundantly in the rock exposed in Brazil

(1) British Assoc. Report, 1886.
(2) Q.J.G.S., Vol. XXXIV. (1878), p. 218.
(3) Proc. Geol. and Poly. Soc., W. Yorks. Vol. IV., p.301, 1863.

Wood.[1] This rock is therefore a biotite-hornblende-granite or hornblende-granitite.

Lake District.—The granites of this district have been described by Mr. WARD.[2] Mr. PHILLIPS has given us some details with regard to the Shap granite.[3] Mr. WARD recognizes three principal granite masses; those of Skiddaw, Shap and Eskdale. There is also a subordinate mass at Wastdale Head. The Skiddaw mass is intrusive in Skiddaw slates which are metamorphosed for some distance from the exposure of granite. The character of this metamorphism will be described in a separate chapter.

The Shap mass affects rocks as high as the Coniston limestone and is therefore post-Ordovician. The Eskdale and Wastdale masses are intrusive in the Borrowdale volcanic series. The Skiddaw mass is composed of a grey granitite sometimes containing conspicuous porphyritic crystals of a white felspar. The Shap mass is remarkable for its large tabular crystals of pink orthoclase. These are almost invariably twinned on the Carlsbad plan. They are uniformly distributed through a coarse-grained granitic matrix which may be either red or grey in colour. The matrix is composed of orthoclase, plagioclase, black mica and quartz with magnetite, titanite, apatite and a little hornblende as accessory constituents. The rock is therefore a porphyritic granitite. Dark patches occur in this granite and the porphyritic felspars often occur in these patches. Their angles, however, are, as a rule, more rounded than in the normal granitite. In several instances Mr. PHILLIPS observed that the large felspars projected beyond the boundary of the inclusions into the main mass of the rock.[4]

In the vast majority of cases the patches are darker in colour and richer in mica and plagioclase than the normal granitite, but here and there patches of a lighter colour almost devoid of black mica were observed.

The margins of the Shap mass are much finer in texture, indeed the rock becomes a micro-granite in ROSENBUSCH'S sense—that is, it consists of porphyritic elements (quartz, felspar and dark mica) in a micro-crystalline ground-mass.

The granite of Eskdale is very different in its characters from that of either of the two localities already referred to. The ferromagnesian constituent (generally dark mica) plays a very subordinate part in the composition of the rock and the quartz and felspar are related to each other in the same manner as they are in the rocks of St. David's and Tan-y-grisiau; that is, the quartz is frequently idiomorphic with respect to the felspar or else the two minerals exhibit a tendency to the micro-pegmatitic structure. Plagioclase is sparingly

(1) See ALLPORT. G.M., Decade II., Vol. VI. (1879), p. 481.

(2) The Geology of the Northern Part of the English Lake District. Mem. Geol. Survey, 1876. Q.J.G.S., Vol. XXXII. (1876), p. 1.

(3) Q.J.G.S., Vol. XXXVI. (1880), p. 9.

(4) Q.J.G.S., Vol. XXXVIII. (1882), p. 216.

represented and the quartz is sometimes seen to be idiomorphic with respect to it; a somewhat unusual feature. A rock from Stony Tarn, collected by Mr. WARD, illustrates the fact that felspar may play the rôle of matrix to quartz in a very perfect manner.

The so-called "syenite" of Ennerdale is a fine-grained pink rock mainly composed of quartz and felspar intergrown as in the granophyres. The ferro-magnesian constituent is feebly represented by green chloritic aggregates. Iron-ores are also very feebly represented. This rock bears a close relation to the granophyres of Mull and Skye. If the term syenite be used in WERNER'S sense it is inapplicable to this rock as quartz enters largely into its composition. There are no decided porphyritic crystals; but the orthoclase which is intergrown with quartz to form what may be termed the ground-mass is often in optical continuity with large patches which have more or less the aspect of porphyritic constituents, as if a considerable amount of felspar substance had first separated as distinct crystals and then the remainder of the felspar substance had intercrystallized with quartz to form the matrix.

	I.	II.	III.
SiO_2 ...	75·223	73·573	71·442
Al_2O_3 ...	11·140	13·750	15·340
Fe_2O_3 ...	tr.	·615	1·230
FeO ...	1·771	2·103	1·107
CaO ...	1·624	1·064	1·064
MgO ...	1·081	·396	·720
K_2O ...	4·516	3·512	4·439
Na_2O ...	3·996	4·315	3·951
P_2O_5 ...	·149	·012	·118
CO_2 ...	tr.	tr.	tr.
Loss ...	·500	·660	·589
	100·000	100·000	100·000

I. Skiddaw granite.
II. Eskdale granite; S. of Great How.
III. Ennerdale granophyre, from Scale Force, near Buttermere. (1)

Cheviot District.—Granitic rocks occur in the central portions of the Cheviot District, about Staindrop Rigg and Hedgehope. The minerals which enter into their composition are orthoclase, plagioclase, quartz, dark mica, augite (malacolite, ROSENBUSCH), iron ores and apatite. The augite is nearly colourless in thin section and similar in character to that of the augite-granitites of the Vosges and the augite-syenites of Monzoni. There is a considerable amount of variability in the relative proportions of the different constituents. Sometimes, as in the neighbourhood of Linhope Spout, the ferro-magnesian constituents are sufficiently numerous to give a dark syenitic or dioritic aspect to the rocks. As a rule, however, they have the aspect of a pink or grey granite of medium grain. Veins of eurite or felsite in which the

(1) The analyses are quoted from Mr. WARD'S Memoir already referred to.

ferro-magnesian minerals are scarcely represented occur in several localities. The plagioclase is often seen to be idiomorphic with respect to quartz and orthoclase, and the two last-mentioned minerals frequently occur in micro-pegmatitic aggregates. The normal rocks are augite-biotite-granites or augite-granitites. They are unlike any other granites known in the British Isles. The more basic rocks, which are somewhat limited in their distribution, have decided affinities with the so-called syenites of Charnwood Forest. These rocks have already been described. Original hornblende has not, however, been detected in the Cheviot rocks. The only hornblendic constituent is a pale green fibrous uralite which has been occasionally developed at the expense of the augite.

Scotland.—The granites of the Southern Uplands are intrusive in lower Palæozoic strata and produce marked contact alteration. The more important masses occur in Kirkcudbrightshire. That of Dalbeattie, which forms a part of the Criffell mass, is greyish white in colour, and may be described as a granitite or hornblende-granitite containing much sphene. The plagioclase frequently shows a zonal structure and is often idiomorphic with respect to quartz. No detailed descriptions of the other masses have as yet been published. A brief account of their mode of occurrence and of the contact metamorphism which they produce will be found in the Survey publications.[1]

Granites abound in the Highlands of Scotland, but much work will have to be done before we are able to separate the different masses according to their relative ages and petrographical characters. Some of these are intimately associated with the crystalline schists (*e.g.*, those of Aberdeen), others are of latter date (*e.g.*, those of Ben Nevis). The grey granites of Aberdeen have been referred to by Professors HAUGHTON[2] and HEDDLE[3] and by Mr. PHILLIPS.[4] They are composed essentially of orthoclase, microcline, a lime-soda felspar (oligoclase according to Professors HAUGHTON and HEDDLE), and two micas.

They are, therefore, true granites in the German sense. Apatite and zircon also occur, and the inclusions in the dark mica are surrounded by the usual dark border. The microcline structure is beautifully shown in many of the felspar sections.

Hair-like crystals (? rutile) occur in the quartz. Mr. PHILLIPS records the occurrence of garnet and sphene. Inclusions and patches of dissimilar character are comparatively rare in these granites. Those described by Mr. PHILLIPS appear to be inclusions of foreign rocks rather than concretionary patches. They are sometimes welded to the enclosing rock; sometimes coated with a layer of mica. Nests of dark mica may, however, be occasionally observed in the Rubislaw quarries.

(1) Explanations to sheets 4 and 9 of the Scotch Survey.
(2) Proc. Roy. Soc., Vol. XVIII., p. 313.
(3) Trans. Roy. Soc. Edin., Vol. XXVIII., p. 265.
(4) Q.J.G.S., Vol. XXXVI. (1880), p. 11.

The granite of Peterhead differs from that of Aberdeen. It is pink in colour and devoid of white mica. It is, therefore, a granitite. The quartz is often idiomorphic with respect to felspar. Patches of finer grain and darker colour occur in the mass. These patches are richer in mica and triclinic felspar than the mass of the rock. Analyses of the normal granite and one of the patches have already been quoted (see *ante*, page 311).

The granite of Beinn Nevis has been referred to by Professor JUDD.[1] It is a granitite, or hornblende-granitite, in which porphyritic crystals of pink orthoclase are often present. The mass is traversed by veins of eurite and felsite.

A specimen from Fort William is rich in sphene and bears the closest possible resemblance microscopically to a rock from the Dalbeattie quarries already referred to as a sphene-bearing hornblende-granitite. Near Ballachulish rocks occur which are intermediate between diorites and hornblende-granitites. One of these has already been described in speaking of the diorites. The igneous rocks of the Beinn Nevis district are regarded by Professor JUDD as the denuded stumps of upper Palæozoic volcanoes.

The author is indebted to Mr. BARROW of the Geological Survey for specimens of the granite and gneissose granite of Beinn Vuroch in Perthshire and for information as to the relations of the different varieties. He is also indebted to the Director General for permission to refer to the specimens. The chief interest of these rocks lies in the fact that they illustrate the gradual passage of granite into gneiss and schist. The normal rock is a coarsely crystalline compound of felspar, quartz and dark mica. The felspar is both striated and unstriated. Much of the striated felspar shows microcline structure. Most of the quartz occurs in large irregular crystalline grains; the remainder is in the granulitic condition. Some of the felspar contains minute well-formed plates of a white mica. These plates are arranged in two or more parallel series. The felspar substance occasionally insinuates itself between the quartz grains. Apatite and zircon are also present. The massive granite passes at its margins into flaser- and augen-gneiss.

The flaser-structure in these rocks is defined by streaks of dark mica and tumid lenticles of quartzo-felspathic material. The white lenticles tail off into the finest strings (see Fig. 1, Plate XLIII.). Under the microscope they are generally seen to contain a large, irregular grain of felspar, showing microcline-structure, surrounded by a granulitic aggregate of quartz and felspar. The tails of the lenticles are formed of this aggregate. The individual grains of the aggregate are mostly uniform in their optic characters, and it is not always possible to decide whether a given grain is composed of quartz or felspar. The use of convergent light will often determine the point and

(1) Q.J.G.S., Vol. XXX. (1874), p. 293.

the fact that quartz possesses slightly higher double-refractive power is also useful.

The dark mica is more abundant in certain wavy planes which sweep round the tumid lenticles above referred to. A pale-coloured mica occurring in good-sized crystalline plates and containing zircon inclusions, surrounded by pleochroic borders, also occurs. Ill-defined crystals and granular aggregates of garnet are not uncommon in the gneissose rocks.

The gneissose rocks differ from the massive rocks so far as they have been examined (1) in the presence of a larger amount of granulitic material, (2) in the presence of a larger amount of light-coloured mica, and (3) in the presence of garnet. The large grains of felspar in the gneissose rocks almost always show microcline structure, whereas those of the massive rocks are often unstriated or only striated after the fashion of ordinary plagioclase. In some of the finer-grained rocks the whole of the quartzo-felspathic material is present in the granulitic condition. Flakes of dark mica, or of dark and white mica, are then seen to lie in a granulitic aggregate of quartz and felspar. The mica-flakes are as a rule much broader than the individual grains of quartz and felspar. Such rocks might be conveniently termed mica-granulites. An interesting question arises as to the origin of the gneissose structures. That they are due to the plastic deformation of a mass of granitic material seems perfectly clear. The only point open to discussion is whether the deformation was produced during or subsequent to consolidation. The author inclines decidedly towards the latter view.

In the Islands off the west coast of Scotland we have, as is well known, granites and felsites of Tertiary age.(1) Professor ZIRKEL(2) has given us some details as to the petrographical characters of these rocks, and Professor JUDD has described their geological relations. The red rocks of Skye, termed syenite by the older authors, were named quartz-syenite and hornblende-bearing or mica-bearing felsite-porphyry by Professor ZIRKEL. They form an extensive tract lying between Sligachan and Broadford. Dykes of basic trap abound in the district; some of these are cut off by the granitic and felsitic rocks, whereas others penetrate these rocks.

The granitic and felsitic rocks are composed, according to ZIRKEL, of orthoclase, plagioclase, quartz, hornblende (here and there some mica), magnetite, apatite and felsite. By felsite he means a substance which cannot be resolved by macroscopic examination. When the felsite is absent we have a fine-grained holo-crystalline rock composed of the above-mentioned minerals. This rock ZIRKEL terms quartz-syenite. The ferro-magnesian minerals do not enter largely into its composition and quartz is generally abundant. The rock is of acid composition. It is not a sub-acid rock as the name syenite appears to imply.

(1) JUDD, Q.J.G.S., Vol. XXX. (1874), p. 220.
(2) Z.D.G.G., 1871, p. 1.

Examples of this type occur on the slope of Marscow facing the Sligachan Valley, on the west slope of Glamaig, on the hill between Glamaig and Sconcer Inn and on Beinn-na-Cailleach. A coarse-grained granitic rock, composed of felspar and quartz, with a little hornblende and black mica, occurs between Kilbride Manse and Loch Slapin.

In other localities the felsitic matter predominates; the crystalline constituents, felspar, quartz and hornblende, occurring as porphyritic elements. The felsite according to ZIRKEL is generally of a grey or greenish grey colour. The quartz of the felsite-porphyries is often well-crystallized and bipyramidal in form. The felspar is much altered and the relative proportion of orthoclase and plagioclase is not constant. In a rock from the north slope of Glamaig plagioclase predominates. Liquid inclusions occur in the quartz and cubes (? salt) are sometimes present in them. Hornblende microlites are frequently scattered through the felsitic matter. The holo-crystalline quartz-syenites and the felsite-porphyries are connected by transitional forms. The felsite of the rock from the north slope of Glamaig is resolved by the microscope into micro-pegmatite. Rocks similar to those of Skye occur also in the Island of Mull. So far we have been quoting Professor ZIRKEL. The author is indebted to Mr. WATTS for a specimen from the east side of Glen Sligachan, Skye, and for two specimens from the base of Craig Craggen in the Isle of Mull. The specimen from Glen Sligachan is a hornblende-granitite. The hornblende (green) is abundant; black mica is scarce. Apatite, iron-ores and sphene also occur. This rock has affinities with the sphene-bearing hornblende-granitites of Fort William and Dalbeattie. The specimens from Craig Craggen are most beautiful examples of augite-bearing granophyres (see Fig. 1, Plate XXXIII.). The one is grey, the other pinkish grey. Both are finely crystalline and granular in appearance. Under the microscope they are seen to be composed principally of quartz and felspar. The ferro-magnesian constituent is a green augite. There is also a little magnetite. The augite and magnetite form an extremely small portion of the entire mass. The felspar is almost entirely orthoclase. It often occurs in Carlsbad twins, both halves of which extinguish simultaneously when the twin-line coincides with one of the cross wires. The orthoclase-individuals lie in a matrix of micro-pegmatite, *and the orthoclase of the micro-pegmatite which immediately surrounds one of the larger individuals generally extinguishes simultaneously with that individual.* This feature has already been referred to in describing the so-called syenite of Ennerdale in the Lake District. The augite occurs in irregular grains. It is richly coloured even in thin section. That it is augite and not hornblende is proved by its cleavage, by its extinction in the zone of the vertical axis (maximum observed 42°) and by the absence of pleochroism. These rocks have the closest affinities with the rock of Barneveve in the Carlingford District (Ireland). They also have affinities with the "micro-granulite" ejected from the

mountain of Krabla[1] in Iceland, with the augitic granophyres of Carrock Fell in Cumberland and with the rock of Ennerdale above referred to. Various sections in the British Museum, prepared from specimens collected by Professor JUDD, agree with the above so that there is every reason to believe that augitic granophyres are largely developed in this island.

Granite is extensively developed in the northern portion of the Isle of Arran. It is a typical granite, or rather granitite, and differs, therefore, from most of the rocks above referred to. Two varieties are recognized: the one coarse-grained, the other fine-grained. Veins of the latter occur in the former. Both are grey in colour. The coarse-grained variety consists, according to ZIRKEL, of orthoclase, plagioclase, quartz and a brownish black mica. Drusy cavities containing white orthoclase and smoky quartz are common. The fine-grained variety is similar in composition. Mica is, however, only sparingly developed and quartz is very abundant. Sections of the Arran granites in the British Museum show that the quartz is often idiomorphic with respect to felspar, and that there is sometimes a tendency to a micro-pegmatitic structure. Indeed the relation of the quartz to the felspar is similar to that of the Dimetian granites. The closest relation exists between the granites of Arran and those of the Mourne Mountains. This is shown not only in the nature and relations of the constituents of the main mass but also in the occurrence in both of drusy cavities containing orthoclase and smoky quartz.

South-east of Ireland. The granites of the main chain are fairly uniform in composition. They consist essentially of two felspars, two micas and quartz.[2] The accessory minerals mentioned by Dr. HAUGHTON are tourmaline, beryl, apatite, garnet, fluor, and spodumene. Mr. JOLY has recently detected cordierite in the Glencullen quarries.[3]

Orthoclase occasionally attains large dimensions and the rock then becomes a porphyritic granite. The ground-mass of the porphyritic granite not seldom assumes a pegmatitic or granophyric structure according to VON LASAULX. Veins of a fine-grained eurite often traverse the main mass. These are sometimes devoid of any micaceous constituent. A secondary schistosity has been developed at the margins of the main mass in certain localities. This may be seen in the neighbourhood of Killiney and Dalkey. The macroscopic and microscopic characters of the schistose rocks are similar to those of the Porthalla "gneiss" above referred to, and a description of the rocks would involve a repetition of what has been already said in speaking of that rock (See Plate XLII.). Some of the rocks in which secondary schistosity has been produced were originally micro-pegmatitic and traces of this texture may still be recognized between the planes along

(1) R. BRÉON. Géologie de l'Island, Paris, 1884.

(2) Dr. HAUGHTON. Q.J.G.S., Vol. XII., p. 171.
Prof. VON LASAULX. T.M.M., Neue Folge. Band I., p. 153.

(3) Proc. Roy. Dublin Soc. 1885., p. 48.

which white mica has been developed. This, however, only occurs in rocks in which the schistosity is imperfect.

The granites in question have marked affinities with those of the West of England. They differ, however, in age, inasmuch as they are undoubtedly pre-Carboniferous. They are intrusive in lower Palæozoic rocks.

Isolated masses of granitic rock occur on a line running roughly parallel to the main range and some distance to the east. As most of these contain an excess of soda over potash Dr. HAUGHTON refers to them as soda-granites. The white rock of Croghan Kinshela has a very remarkable composition. It is supposed by Dr. HAUGHTON to be composed essentially of quartz and albite (38% of quartz and 62 of albite). A small amount of chlorite is occasionally present.

	I.	Extremes.			II.
SiO_2	72·084	70·28	...	73·24	80·24
Al_2O_3	14·459	12·64	...	16·44	12·24
Fe_2O_3	2·399	1·40	...	3·47	0·72
CaO	1·762	0·96	...	2·84	0·89
MgO	0·105	0·11	...	0·53	tr.
K_2O	4·803	5·90	...	3·95	0·40
Na_2O	3·014	2·31	...	3·53	5·58
Loss	0·906	0·96	...	1·39	—
	99·532				100·07
Sp. Gr.	2·634	2·616		2·652	2 629

I. Average of nine analyses, the extremes of which are quoted, of the granite of the main chain.

II. Soda-granite of Croghan Kinshela. It was in the alluvial deposits of the streams flowing from Croghan Kinshela that gold was found in considerable quantities at the end of the last century. No gold was ever found *in situ*.

North-east of Ireland. These granites occur in three isolated districts of considerable size on the borders of the counties of Down, Louth and Armagh. They are very different in character from those of Leinster. That of the Carlingford district is certainly of post-Carboniferous age. The granites of the Mourne mountains have decided affinities with those of Arran, while the granites of the Carlingford district (including the granophyre of Barneveve) resemble those of Mull and Skye. These petrographical resemblances are probably an indication of contemporaneity.

The granite of the Mourne Mountains is composed of two felspars, quartz and a dark mica. It is usually fine in grain but often contains drusy cavities in which the constituents occur in a well-crystallized form and attain considerable dimensions. The principal minerals of these cavities are white orthoclase, albite and smoky quartz. The accessory minerals are beryl, chrysoberyl, octahedral fluor, topaz and peridote (HAUGHTON). A rock from Rostrevor is a fairly coarse-grained, grey granitite. Idiomorphic quartz occurs as inclusions in the felspar and much of the quartz is seen to be idiomorphic with respect to the felspar. The dark mica is very strongly pleochroic and often contains minute grains of zircon. The

rock of Slieve Donard is similar in character but somewhat more coarsely crystalline. Another specimen from an unknown locality in the Mourne Mountains furnishes a magnificent illustration of micro-pegmatitic structure. In the absence of white mica as an original constituent and in the mutual relations of the quartz and felspar the granite of the Mourne Mountains possesses affinities with the Dimetian granites of Wales and with the Eskdale granite in the Lake District. In the occurrence of drusy cavities containing white orthoclase and smoky quartz it resembles the granite of Arran.

	I.		II.		III.		IV.
SiO_2	66·25	...	68·97	...	43·42	...	75.00
Al_2O_3	17·35	...	19·23	...	19·00	...	13·24
Fe_2O_3	—	...	—	...	17·64	...	2·52
CaO	1·25	...	1·21	...	1·81	...	0·69
MgO	0·05	...	0·24	...	0·54	...	—
K_2O	11·22	...	1·56	...	8·77	...	4·33
Na_2O	3·05	...	8·71	...	3·66	...	3·07
Loss	0·30	...	—	...	4·30	...	0·80
	99·47		99·92		99·14		99·65

I. Orthoclase from granite of the Mourne Mountains—average of three analyses by Dr. HAUGHTON.

II. Albite from same rock.

III. Mica from same rock.

IV. Bulk analysis of the rock.

The granites of the Carlingford district, according to Dr. HAUGHTON, belong to two varieties; the one composed of quartz, felspar and green mica, the other of quartz, felspar and hornblende. The granites of the Newry district are also divided by Dr. HAUGHTON into two groups; the potash-granites and the soda-granites. The latter appear to have affinities with the diorites. A felsite dyke traverses the granite of Newry Quarry.

	I.		II.		III.		IV.
SiO_2	70·48	...	71·41	...	63·34	...	74·20
Al_2O_3	14·24	...	12·61	...	15·28	...	10·84
Fe_2O	3·72	...	4·76	...	6·88	...	1·88
CaO	1·48	...	1·80	. .	4·34	...	2·84
MgO	0·40	...	0·63	...	2·48	...	tr.
K_2O	4·26	...	5·47	...	2·67	...	3·12
Na_2O	3·66	...	3·03	...	3·68	...	4·77
Loss	1·59	...	—	...	1·01	...	0·83
	99·83		99·74		99·68		98·48
Sp. Gr.	2·593		2·632		2·713		—

I. Medium-grained granite from base of Slieve-na-glogh, Carlingford.

II. Fine-grained granite from Grange Irish, Carlingford.

III. "Soda-granite" from Newry district mean of two analyses. The "potash-granites" of this district resemble in composition the medium-grained granite of Slieve-na-glogh.

IV. Felsite dyke in Newry Quarry.

The granites of the Newry district have been examined by Mr. J. A. PHILLIPS.[1] The "white" granite of Newry is, according to this author, a compound of quartz, orthoclase and dark mica. The "blue granite" of Goragh Wood contains in addition hornblende, plagioclase and sphene. It is therefore a sphene-bearing hornblende-granitite. Foreign inclusions and concretionary patches occur in this rock.

North-west of Ireland.—The gneissose granites of Donegal have also been examined by Dr. HAUGHTON. They are banded and the general strike of the banding is about 10° or 15° S. of W. The essential constituents are quartz, orthoclase, oligoclase and black mica. White mica and hornblende are occasionally present. The accessory minerals are sphene, tourmaline, beryl, garnet, molybdenite and copper pyrites. Fifteen analyses are given.[2] These show a much greater variability in composition than those of the normal intrusive granites of the east of Ireland. Some of the rocks analysed were of intermediate composition.

The microscopic characters of the granite of Galway, which is also gneissose, have been described by Professor HULL.[3] It is rendered porphyritic by the occurrence of flesh-coloured orthoclase. The principal constituents are orthoclase, microcline, oligoclase, quartz and dark mica. Colourless mica occurs in twisted flakes. Normal intrusive granite of uniform texture occurs in Co. Mayo. That of Aillemore[4] is composed of quartz, orthoclase, microcline, oligoclase (?) and dark green mica. It occasionally shows a graphic structure.

A slide of gneissose granite from the neighbourhood of Galway, in the author's possession, shows orthoclase, plagioclase, dark mica hornblende, granulitic quartz, sphene and apatite. The granulation of the quartz is probably the result of dynamic metamorphism.

We have now to consider the Trachytic Rocks. Under this head we include the felsites, quartz-felsites, liparites or rhyolites, obsidians and pitchstones. These rocks occur as intrusive sheets, dykes and lava-flows, and less frequently as irregular intrusive masses. It is impossible to decide as to whether any particular rock is an intrusive mass or a lava-flow by reference to petrographical characters alone. The occurrence of a marked fluidal structure is, however, more common in the lavas than in the intrusive rocks. The acid lavas are distinguished from the basic lavas by a greater want of homogeneity. They frequently exhibit a remarkable banded or laminated structure in consequence of the variation in texture and composition of successive layers. Very frequently the laminæ are crumpled and contorted in a most remarkable manner. These banded structures are equally characteristic of both ancient and modern rocks of similar composition. They are found in the ancient Ordovician

(1) Q.J.G.S., Vol. XXXVI. (1880), p. 16.
(2) Q.J.G.S., Vol. XVIII., p. 408.
(3) G.M., Decade I., Vol. X. (1873), p. 193.
(4) HULL; Jour. Geol. Soc., Ireland, Vol. IV., p. 4.

lavas of Snowdon and in the comparatively recent lavas of the Ponza Isles so admirably described by SCROPE. The lamination is undoubtedly the result of the deformation of a heterogeneous mass of plastic material. Acid lavas when erupted at the surface are in a state of imperfect fluidity, so that a perfect mixing of the portions which differ in composition and physical properties is impossible. Thus, as the whole mass takes the form of a flat sheet or elongated tongue, according to the configuration of the surface near the point of eruption, the individual portions of the mass take a corresponding form and a banded or laminated structure is the result. If, as frequently happens, the deforming influences are not uniform in their operation crumplings and contortions are produced; and, in the extreme case, the more or less consolidated portions are broken up and brecciated lavas are formed.

Intimately associated with the different exposures of granite we find veins and dykes of a rock largely composed of a substance which cannot be resolved into distinct constituents by the naked eye. This is the felsite of petrographers. Sometimes the rock is wholly composed of felsite; more frequently we find porphyritic crystals of quartz, felspar and one of the ferro-magnesian minerals occurring as porphyritic constituents. The felspar may be monoclinic or triclinic. The monoclinic felspar is usually in the condition of orthoclase. When quartz occurs as one of the porphyritic constituents the rock is termed quartz-felsite or quartz-porphyry; when quartz is absent as a porphyritic constituent and orthoclase present the rock is termed orthoclase-felsite, orthofelsite, or orthophyre. The examination of thin slices under the microscope frequently enables one to resolve the felsitic matter into an aggregate of crystalline constituents. This, as we have already seen, has led to a subdivision of the porphyritic-felsites into micro-granites, granophyres and felsophyres. In the micro-granites the felsite is composed of an aggregate of granitic minerals arranged without any regularity; in the granophyres it is mainly composed of quartz and felspar intergrown so as to form micro-pegmatitic or pseudo-spherulitic aggregates; in the felsophyres it is variable in character and incapable of precise definition.

When a mass of granite is traced towards its margin and from thence into the apophyses which run out into the surrounding rocks it is often seen to pass into micro-granite, granophyre, or felsophyre; sometimes into a felsite without porphyritic constituents. Felsitic dykes may sometimes be seen to cut both granite and the surrounding rocks, and when this is the case the felsite is frequently similar to a rock which occurs as contemporaneous veins in the granite. The occurrence of glass as a constituent of the dykes and veins which can be directly connected with granite masses is rare, but it has been observed by LOSSEN [1]

(1) Die Bode-gang im Hartz, Z.D.G.G. (1874), Vol. XXVI., p. 856.

We will now give an account of the British trachytic rocks of acid composition.

West of England.—The "elvans" of Cornwall have been described in general terms by Mr. J. A. PHILLIPS.[1] We copy his description verbatim. It will apply equally to the elvans of Devonshire. "The elvans of Cornwall are rocks occurring in veins or dykes, which have almost identically the same ultimate chemical and mineralogical composition as the granites of the district; the aggregation of their constituents, however, is often very different.

"In elvans, the quartz, instead of forming, as in granite, a kind of crystalline residual base, is usually, together with felspar, porphyritically enclosed, in the form of crystals, in a felspathic or quartzo-felspathic base; mica, schorl and chlorite are often present to some extent, while pinite is by no means an unfrequent accessory. Graphite in the form of small nodular masses is sometimes found in Cornish elvans. The quartz-crystals of elvans are often double hexagonal pyramids connected at the bases by a short prism. These, which are either glassy and transparent, white and opaque, or somewhat smoky, have often rounded angles. This removal of the edges is sometimes so complete that the patches of quartz in an elvan present the appearance of mere gumlike blebs. . . . . .

"The felspar in elvans is often in the form of large, well-defined crystals, which may be either transparent and colourless, or white, pink, red, or grey; in other varieties the crystals are very minute, and can only be discovered by the aid of a lens. They are readily decomposed by weathering into kaolin; and the cavities resulting from its subsequent removal are sometimes lined with göthite. More frequently they have been re-filled with schorl or chlorite; while, in the well-known pseudomorphs of Huel Coates, felspar has been replaced by cassiterite.

"Schorl occurs either as isolated crystals or in stellate groups. Mica is often disseminated through the mass; but in some cases, particularly in the coarse-grained elvans, it is found in crystalline aggregations.

"Elvan courses vary in width from a few feet to several fathoms; they are more numerous in the vicinity of granite than elsewhere, and traverse alike both granites and slates. They frequently conform, both in direction and in dip, to one series of joints in the rocks which they traverse; but they seldom penetrate between the cleavage planes of slates.

"In slate they generally consist of a compact felspathic or quartzo-felspathic base containing crystals of felspar and crystalline or gum-like patches of quartz. When enclosed in granite, a similar base prevails, mica and schorl are frequently present, and porphyritically-embedded crystals are numerous, but the rock is generally finer-grained than when it is in the slate. In both rocks, however, it is usually coarser and more porphyritic near the middle of the dyke than towards its sides.

(1) Q.J.G.S. Vol. XXXI. (1875), p. 334.

"Elvans are traversed in all directions by joints dividing them into irregularly-shaped blocks; in some cases these are filled with schorl, while in others the filling material is a ferruginous or felspathic clay.

"Throughout the principal mining districts of Cornwall the general bearing of the elvan-courses is a few degrees north of east, and they are therefore approximately parallel with the majority of the most productive tin and copper lodes. In other parts of the county elvans are sometimes found running nearly north and south, thus nearly coinciding in direction with the cross veins occasionally yielding lead and iron-ores."(1)

Mr. PHILLIPS gives three analyses of the E. and W. elvans (quartz-felsites).

	I.	II.	III.
SiO_2 ...	72·51	72·82	71·46
Al_2O_3 ...	13·31	15·12	15·38
Fe_2O_3 ...	tr.	1·75	·30
FeO ...	3·87	tr.	2·27
MnO ...	·62	tr.	tr.
CaO ...	·60	·52	·47
MgO ..	1·52	1·06	·22
K_2O ...	6·65	6·25	5·51
Na_2O ...	·43	·51	2·79
Fl ...	tr.	—	—
H_2O ..	·60	2·29	1·70
	100·11	100·32	100·10
Sp. Gr. ...	2·62	2·64	2·65

I. "Elvan" dyke, Sydney Cove, Pra Sands, near Marazion. The rock from the centre of the dyke is rendered conspicuously porphyritic by the occurrence of large crystals of white and pink felspar. Quartz, mica, tourmaline and pinite also occur. Under the microscope the quartz is seen to be sometimes idiomorphic, sometimes in the form of more or less rounded grains with inlets and inclusions of the ground-mass. The porphyritic orthoclase is sometimes surrounded by a border of micro-pegmatite, and sometimes bounded by sharp crystallographic outlines. The pinite often shows the form of cordierite. It is an aggregate of green or yellowish-green micaceous flakes which give the yellows, reds and blues of the first order under crossed nicols. The ground-mass is micro-crystalline, so that the rock would be a pinitiferous micro-granite in ROSENBUSCH's sense. Flakes of mica are scattered through the ground-mass. The margin of the dyke is less-markedly porphyritic. It is compact and sometimes banded. The ground-mass is crypto-crystalline. Idiomorphic tourmaline occurs in the ground-mass.

II. Dyke in granite of Tregoning Hill. The porphyritic constituents are the same as those of the last-mentioned rock. The ground-mass is crypto-crystalline according to Mr. PHILLIPS.

III. Dyke in Killas near Hayle. "Its general colour is a dull bluish-grey; it encloses a few distinct crystals of white felspar and occasionally small nests of flaky graphite. The amount of porphyritically embedded quartz is exceedingly small" (PHILLIPS).

The ground-mass of the rocks now under consideration is generally micro- or crypto-crystalline; rarely granophyric. The rocks therefore are mostly micro-granites or felsophyres. Typical granophyres have not as yet been observed.

Wales.—The Dimetian rock of St. David's is associated with felsites and quartz-felsites which often show pseudo-spherulitic and spherulitic

(1) These north and south "elvans" are not, at any rate as a rule, quartz felsites but "mica-traps," a totally different class of rocks. They will be described in a separate chapter.

structures, and sometimes also micro-pegmatitic structures. These rocks are regarded by Dr. GEIKIE as forming the peripheral portion of the granite. They have been described by Messrs. TAWNEY[1] and DAVIES,[2] by Dr. GEIKIE[3] and Professor BLAKE.[4]

Professor BLAKE distinguishes two varieties, the "spotted felsite" and the quartz-felsite. The porphyritic crystals of the former are mainly felspar. The ground-mass is minutely spherulitic or micro-crystalline. The spherulites have, as a rule, a well-defined periphery and give a fixed black cross. They are independent of the porphyritic constituents (felspar and quartz) so far as their distribution is concerned. The porphyritic crystals of the latter are both quartz and felspar (often striated); the spherulites are large, without a well-defined black cross, devoid of sharp outlines and grouped round the porphyritic constituents. The quartz occurs in the corroded forms characteristic of the felsites and liparites. The matrix in which the porphyritic constituents with their spherulitic appendages lie is micro-crystalline. Epidote is common in both varieties, and often occurs in radiating sheaves. It is an unfortunate circumstance that there is a difference of opinion as to the geological relations of the rocks above described. Dr. GEIKIE regards them as the apophyses of the granite; Dr. HICKS on the other hand speaks of them as rhyolitic lavas. Both observers agree, however, that there are fragmental rocks of acid composition in the St. David's area, and Dr. GEIKIE gives the analyses of three rocks which he classes as felsitic tuffs.

	I.		II.		III.
SiO_2	80·59	...	73·42	...	72·63
Al_2O_3	11·29	...	12·09	...	16·23
Fe_2O_3	0·28	...	0·91	...	2·70
FeO	1·41	...	3·13	...	0·48
MnO	tr.	...	0·25	...	—
CaO	0·52	...	2·94	...	0·18
MgO	0·95	...	1·12	...	1·36
K_2O	2·98	...	1·67	...	3·35
Na_2O	0·72	...	3·88	...	0·15
Loss	1·96	...	1·28	...	3·04
	100·70	...	100·69	...	100·12
Sp. Gr.	2·55	...	2·74		

I. Greenish felsitic breccia, Clegyr Hill. Rock composed of angular fragments of various felsites embedded in a greenish matrix. Analysis by Mr. WILSON.

II. Grey felsitic tuff, north of the bridge over the Allan river, north from the Schools, St. David's. Analysis by Mr. WILSON.

III. Pale pinkish-white, finely schistose tuff, a characteristic sample of the "Porth-lisky schists." Analysis by M. RENARD.

(1) Proc. Bristol Naturalists' Soc., Vol. II., Part 2.
(2) Q.J.G.S., Vol. XXXIV. (1878), p. 164.
(3) Q.J.G.S., Vol. XXXIX. (1883), p. 315.
(4) Q.J.G.S., Vol. XL. (1884), p. 303.

Some of the felsitic tuffs of the St. David's area have been converted into sericitic schists by the dynamic metamorphism which has affected the district.

Felsitic rocks have been described by Professor BLAKE as occurring in Ramsey Island. One of these exhibits perlitic structure in great perfection although the rock is now devitrified.

Felsites are known to occur in many other localities in South Wales. On the west side of Goodwic Bay, near Fishguard, there is a fine exposure of banded and brecciated felsites associated with felsitic agglomerates. Nodular and banded felsites are seen on the south side of Skomer Island. The nodules in these rocks vary in size from minute globules, no larger than small peas, to spherical masses measuring several inches in diameter. They are sometimes solid to the core, at other times they contain a hollow cavity on the surface of which quartz-crystals have been formed. A radial structure may occasionally be observed, but as a rule it is absent. Bands in the felsite may often be followed through the nodules. Under the microscope the matrix in which these nodules lie occasionally shows perlitic structure although it is now completely devitrified. There can be no doubt that we have here a group of ancient probably Ordovician) devitrified glassy rocks.(1)

North Wales.—Felsites and felsophyres occur in North Wales. They belong to two distinct periods—the Cambrian or pre-Cambrian and the Ordovician. Those of Cambrian or pre-Cambrian age have been described by Professor BONNEY (2) as devitrified rhyolites. They are well exposed near Llyn Padarn and between Caernarvon and Bangor. They consist of porphyritic crystals and crystal-fragments of quartz, orthoclase and plagioclase embedded in a compact grey or purple matrix. Under the microscope they frequently show the fluxion structure of rhyolites. The ground-mass is usually crypto-crystalline. A ferro-magnesian constituent is not definitely recognizable. An analysis of one of these rocks from Brithdir near Bangor is quoted below. The specific gravity of a specimen from Cwm-y-glo near Llanberis is 2·61.

The Ordovician felsites and felsophyres are extensively developed both in Merionethshire and Caernarvonshire. They have been described by Messrs. WARD,(3) RUTLEY,(4) BONNEY(5) and COLE.(6)

They are generally compact, dark grey, greenish grey or bluish grey rocks which exhibit a marked tendency to weather white. Small felspars may frequently be detected, but the rocks rarely become conspicuously porphyritic. Quartz is certainly rare as a porphyritic constituent—a fact which appears somewhat remarkable when we take

(1) RUTLEY. Felsitic Lavas. Mem. Geol. Survey, 1885.

(2) Q.J.G.S., Vol. XXXV., p. 309; Vol. XXXIV., p. 137; and Vol. XXXIX., p. 478.

(3) Q.J.G.S., Vol. XXXI. (1875), p. 388.

(4) Q.J.G.S., Vol. XXXV. (1879), p. 508; and Vol. XXXVII.(1881), p. 403.

(5) Q.J.G.S., Vol. XXXVIII. (1882), p. 289.

(6) Q.J.G.S., Vol. XLI. (1885), p. 162; and Vol. XLII. (1886), p. 183.

into consideration the highly siliceous character of these rocks. In specific gravity they range from 2·6 to 2·7; the average lying nearer the former than the latter. The mode of occurrence of these rocks is described in the Survey Memoir on North Wales. They are in many cases undoubtedly lavas; and they frequently exhibit the banded vesicular, spherulitic and nodular structures so characteristic of lavas of acid composition. The discovery of perlitic structure in the rocks of the Glyders (Esgair-felen) and Snowdon (Clogwyn d'ur Arddu) by Mr. Rutley has demonstrated the fact that some of them were originally obsidians or pitchstones. No distinct traces of glass now remain. The rocks have been completely devitrified. Under crossed nicols they give a crypto-crystalline, micro-crystalline or confusedly crystalline reaction. Sometimes large irregular patches give uniform extinction. The boundaries of these patches are, however, never well-defined in ordinary light, and even under crossed nicols they are wanting in sharpness. Granules of opacite, ferrite or viridite are frequently scattered through the mass without any regard to the double-refracting portions. Glassy lavas frequently show a want of uniformity. Bands and intricate convolutions are often apparent owing to a variation in the physical properties of the glass. These structures are not seen under crossed nicols because every portion of the glass appears dark. Precisely similar structures may be seen in the Snowdonian felsites, as, for example, in those occurring near Pitt's Head not far from the Beddgelert road. Here, however, they may be seen under crossed nicols in consequence of the fact that the different varieties of glass in the original rock have given rise to different devitrification-structures. If we compare the felsitic lavas of the Snowdonian area with the vitreous lavas of more recent geological periods we note in both the occurrence of vesicular, banded, spherulitic, nodular, perlitic and fluxion structures. The felsitic lavas differ, however, in being stony and in possessing a higher specific gravity—say 2·6 as against 2·4.

In speculating on the possible causes of devitrification it is well to observe that the rocks in question have been involved in the earth-movements that have so powerfully affected the district. In certain localities a schistosity has been developed and sericite has been formed along definite planes and in the mass of the felsite. To such an extent has this proceeded that the rocks in certain places have become sericitic schists.[1] The term "porphyroid" is applied on the Continent to felsites of all kinds which have become more or less schistose in consequence of dynamic metamorphism and in which secondary micaceous minerals, especially sericite, have been developed. The schistose felsites of Wales resemble the "porphyroids" of the Ardennes [2] and

(1) See Bonney, Q.J.G.S., Vol. XXXVIII. (1882), p. 289.

(2) De la Vallee Poussin et Renard. Mémoire sur les roches dites plutoniennes, &c. A von Lasaulx. Sitz. d. Niederrhein. Gesell. August, 1884.

the Thuringerwald.[1] In describing the basic igneous rocks of North Wales it was shown that they locally become schistose and sometimes pass into a chloritic schist In the same way the acid rocks locally become schistose and sometimes pass into sericitic schists. Now, seeing that devitrification is accompanied by an increase in density it is reasonable to suppose that intense mechanical stresses would tend to bring about devitrification. The devitrification of the Ordovician obsidians and pitchstones is therefore possibly a phenomenon of dynamic metamorphism.

The nodular character of many of the felsites of North Wales is a somewhat striking feature. The nodular felsites have especially engaged the attention of Dr. BONNEY and Mr. COLE. The "nodules" lie in a felsitic matrix in which fluxion structure is often well-defined. They may be solid or hollow. In the latter case the cavities are often lined with quartz crystals. Sometimes the cavities have been entirely filled with quartz. In the cases examined by Dr. BONNEY the material of the nodules was similar to that of the felsite. There was no trace of radial structure. Mr. COLE records the occasional presence of radial structure. The two observers above-mentioned differ as to the origin of the cavities. According to the former they are original, according to the latter they have been formed by the decomposition of solid spherulites. That they are analogous to the "lithophysæ" of VON RICHTOFEN will be admitted, and it is interesting to observe that the same difference of opinion exists with regard to the origin of these structures. A discussion of the question so far as it affects the origin of the lithophysæ of vitreous rocks will be found in a paper by Mr. J. P. IDDINGS.[2] This author concludes that the lithophysæ in the obsidian of the Yellowstone region, containing quartz, tridymite, acid felspar (soda-orthoclase) and fayalite, are due to the liberation of gases and vapours accompanying the crystallization of the spherulites. If this view be generally applicable then hollow spaces should occur only in those spherulites which are crystalline in texture. It will not explain the occurrence of hollow spaces in those nodules which are similar in structure and composition to the surrounding rock. Professor BONNEY'S observations on the nodular felsites of North Wales led him to the conclusion that the nodular structure had been produced in two ways:—

(1) By simple contraction and roughly concentric cracking of the mass on cooling, being thus intermediate between the perlitic structure common in glassy acid lavas, and the spheroidal structure common in basalt.

(2) By similar contraction in cooling, which is determined by the presence of a cavity, and produced as follows:—When the cavity is

(1) H. LORETZ. Jahr. d. k. preuss. Geol. Landesanstalt für 1881, p. 175. Berlin, 1882.
(2) A.J.S., 3rd Series, Vol. XXXIII., 1887, p. 36.

first formed, we may regard the whole viscid mass in the neighbourhood as in a state of equilibrium between the various forces acting on the cooling lava (contraction, &c.) and the pressure of the gaseous contents of the cavity. As cooling proceeds (uniformly suppose) pressure of the latter against the walls of the cavity diminishes rapidly. The various forces are no longer in equilibrium, and the contractile strain will be relieved by the formation of a crack, roughly concentric with the cavity, which, as we might expect, is more regular than it in form.

The nodules vary in size from that of peas to globes measuring four or five inches in diameter. They have sometimes been flattened by crushing. A soft black substance is occasionally found associated with them. It is sometimes arranged in successive concentric zones. This substance has been analysed by Mr. Cole. Examples of nodular felsites occur in the Pass of Llanberis, near Pont-y-Gromlech; at the Conway Falls Inn; at Digoed and at Conway Mountain.

Porphyritic constituents, as we have already stated, are rarely conspicuous in the Ordovician felsites and felsophyres. Small crystals of both orthoclase and plagioclase may, however, be frequently recognized under the microscope. In some rocks plagioclase alone occurs. This is the case in a nodular felsite from Pont-y-Gromlech. The felsophyre of Arenig is interesting as being conspicuously porphyritic. Macroscopically it consists of white felspar crystals rarely measuring more than 3 mm. across, soft dark spots evidently representing a ferromagnesian constituent and a compact greenish-grey matrix. Under the microscope both orthoclase and plagioclase may be recognized. They occur in isolated crystals and in groups. The dark spots are chloritic pseudomorphs after pyroxene. The ground-mass is confusedly crystalline, but it is largely composed of somewhat ragged acicular microlites of felspar which often extinguish at considerable angles. This rock in structure and composition is intermediate between the trachytes and andesites.

	I.	II	III.	IV.	V.	VI.	VII.
SiO_2	72·57	83·302	74·88	79·72	83·08	50·75	68·8
Al_2O_3	13·64	7·686	12·00	9·65	10·25	28·34	14·9
Fe_2O_3	2·28	·111	3·50	5·69	tr.	3·63	·9
FeO	—	·408	0·20	—	—	—	4·3
BaO	tr.	—	—	—	—	—	—
CaO	1·00	·896	0·34	not est.	·26	2·57	1·9
MgO	·64	·109	1·28	not est.	·09	1·85	1·1
K_2O	6·17	2·161	4·77	1·93	1·78	6·21	2·8
Na_2O	2·07	4·229	2·49	3·54	3·58	2·19	2·7
FeS_2	—	·191	—	—	—	—	—
Loss	1·10	·301	1·20	—	·74	4·37	2·0
	99·47	99·894	100·66	100·53	99·78	99·91	99·4

I. Purple quartz-felsite (pre-Cambrian) from Brithdir Farm, near Bangor. Analysis by Teall. Q.J.G.S., Vol. XXXIX., p. 485.

II. Felsophyre from summit of Aran Mowddwy. Contains porphyritic felspar-crystals in a

felsitic matrix. Analysis by J. HUGHES. Q.J.G.S., Vol. XXXI, p. 400. The analysis is made up to 100 by ·089 of phosphoric acid and ·017 of sulphuric acid.

III. Pale green felsite near Pitt's Head. Analysis by HAUGHTON. Trans. Roy. Irish Acad., Vol. XXIII., p. 615.

IV. Matrix of nodular felsite from the Lledr Valley, near Conway Falls Inn. Q.J.G.S., Vol. XXXIX, p. 485. Analysis by HATCH.

V. White spherulitic rock. Digoed near Penmachno. Q.J.G.S., Vol. XLII, p. 187. Analysis by COLE.

VI. Black layer in large spherulite, Digoed. Substance allied to pinite. Analysis by COLE.

VII. Orthofelsite. Arenig. Analysed by Mr. PLAYER, in the author's laboratory.

Midland Counties.—Near Wellington, in Shropshire, occur the remarkable devitrified rhyolites and rhyolitic tuffs described by Mr. ALLPORT.[1] These rocks are probably of pre-Cambrian age; at any rate they are overlain unconformably by stratified rocks as old as the Holybush sandstone. They are of great importance in the history of petrography because they enabled Mr. ALLPORT, in 1877, to demonstrate the existence in very early times of perlitic and spherulitic hyaline rhyolites, identical with those of Hungary. The most striking variety described by Mr. ALLPORT from the "Lea Rock" quarry "consists of numerous bright red spherulites set in a grey or yellowish green matrix." The spherulites sometimes occur singly; more frequently they are aggregated together in patches or bands. Where they have been freely developed they usually show, in thin section "a circular central disk of bright red surrounded by a colourless (or pale red) ring: the latter varies greatly in width and is perfectly continuous with the red portion, of which it is the unstained border." They are radially fibrous and give a black cross. In the character of their double-refraction these spherulites differ from the small colourless spherulites found in many felsites. They are positive: in other words they behave as if they were composed of uniaxial and positive fibres. In the aggregate of spherulites the development of a regular and radially fibrous arrangement is considerably interfered with, and very often no definite structure is recognizable. The red bands are frequently seen to widen out at their terminations Where the radial structure is imperfect the double-refraction is scarcely, if at all, recognizable. A few porphyritic crystals of felspar occur in the rock. These have exercised no influence on the grouping of the spherulites. The substance which has formed the spherulites is the micro-felsite of ROSENBUSCH. In their internal structure and relation to the surrounding matrix the spherulitic bodies are identical with those of the rhyolites (lithoidit) of Szanto and Tolesva in Hungary.[2]

The matrix in which the porphyritic crystals and spherulitic bodies lie is devoid of the red colouring matter (ferrite). It often shows perfect perlitic structure. The perlitic cracks are frequently occupied by a green substance (viridite or chlorite) and the same substance is often scattered

(1) Q.J.G.S., Vol. XXXIII., 1877, p. 449.

(2) VOGELSANG, Die Krystalliten, p. 117.

through the mass. Under crossed nicols it (the matrix) usually gives a micro-crystalline reaction. There is nothing, however, in its aspect in ordinary light to indicate that it is a crystalline aggregate; the boundaries of the grains are totally unrecognizable. In addition to the constituents already mentioned this rock contains margarites, trichites and longulites. These bodies are arranged with their longer axes roughly parallel to each other. They occur both in the spherulites and in the devitrified glass and their parallelism has not been affected by the development of the spherulites. They are largest, however, in the nearly colourless zone surrounding the spherulites. The following is the succession of events as deduced from a study of the microscopic structure of this interesting rock:—

(1) Formation of the porphyritic felspar crystals.

(2) Development of microlites and of fluxion structures.

(3) Development of spherulitic structures.[1]

(4) Consolidation of the residual magma as glass and the formation of perlitic cracks.

(5) Devitrification of the glass and deposition of chlorite (?) in the cracks (See Figs. 1 and 2, Plate XXXIV.).

From the same quarry as that in which the spherulitic felsophyre occurs Mr. ALLPORT obtained excellent specimens of devitrified perlites (perlitic felsites).

Felsites occur in the Malvern Hills and Dr. CALLAWAY[2] has recently called attention to the passage of these into micaceous (? sericitic) schists.

A quartz-felsite occurs below the Cambrian rocks of Nuneaton.[3] It contains porphyritic crystals and grains of quartz (often corroded) and felspar in a matrix which shows fluxion structure. Portions of the mass have a brecciated aspect.

Professor BONNEY[4] has described rhyolitic tuffs from the Charnwood Forest district in Leicestershire.

	I.	II.	III.	IV.
SiO_2	72·18	72·19	72·52	73·00
Al_2O_3	14·46	14·44	13·72	12·31
Fe_2O_3	1·78	1·59	20·8	2·05
FeO	0·91	0·91		
MnO	tr.	tr.	—	—
CaO	0·92	0·93	1·15	1·20
MgO	tr.	tr.	0·45	1·47
K_2O	6·10	6·14	5·68	5·96
Na_2O	1·92	1·96	1·15	1·36
H_2O	1·47	1·46	3·50	2·90
	99·74	99·62	100·25	100·25
Sp. Gr.	2·62	—	2·394	2·384

(1) According to VOGELSANG and ROSENBUSCH the formation of ferrite in the spherulites must be referred to this stage. It is due, accordiug to these authors, to the squeezing out of the iron oxide by the crystallization of the felsite.

(2) Q.J.G.S., Vol. XLIII. (1887), p. 530.

(3) WALLER, G.M. (1886), p. 323. RUTLEY, G.M. (1886), p. 559.

(4) Q.J.G.S., Vol. XXXVI., p. 337.

I. & II. Duplicate analyses by Mr. PHILLIPS of the devitrified perlitic pitchstone from the "Lea Rock" quarry. Q.J.G.S., Vol. XXXIII., p. 457.

II. Perlite from Hlinyik, near Schemnitz. Analysed by VON SOMMARUGA.

III. Perlite from same locality. Analysed by RAMMELSBERG.(1)

On comparing the above analyses it will be seen that the devitrified rocks contain less water. There is also a marked difference in specific gravity. In other respects there is the closest possible resemblance between the ancient and modern rocks. The significance of the difference in specific gravity has already been discussed (see *ante* page 13).

The Lake District. Rocks of the group now under consideration occur in this district in two forms (1) as dykes and intrusive masses and (2) as lava-flows. The former have been described by Mr. WARD in his memoir on the northern part of the Lake District. The Armboth dyke is composed of a biotite-quartz-felsite. Crystals of pink orthoclase give the rock a marked porphyritic character. Plagioclase is also present. The ground-mass shows micro-pegmatitic or pseudo-spherulitic structures so that the rock is a granophyre in Rosenbusch's sense. Here and there it contains minute but well-formed dodecahedra of garnet. The occurrence of garnet and pinite (pseudomorph after cordierite) in the quartz-porphyries is interesting because these minerals occur also in the liparites.(2) The latter mineral is not known in the Armboth dyke but it has been found in some of the Cornish "elvans." Mr. WARD records the occurrence of several other intrusive quartz-felsites in the Lake District. They are probably connected with the masses of granite.

The rock from the summit of Carrock Fell is a beautiful example of an augite-bearing granophyre. This is the spherulitic felsite of WARD. It stands in close relation to the quartz-gabbro or augite-diorite.

A mass of quartz-felsite is extensively quarried near Threlkeld. It contains porphyritic quartz and felspar, with some dark mica, in a crypto- or micro-crystalline ground-mass. The lavas are associated with the Coniston limestone. They correspond therefore with the Ordovician felsites of North Wales. Mr. RUTLEY has described some of them in his memoir (3) on "The Felsitic Lavas of England and Wales."

Perlitic structures have been observed in felsites from the Red Crag, one and a half miles N.E. of Stockdale in Westmoreland, the northern end of Long Sleddale Valley, the neighbourhood of Grizedale Tarn and the Copper Mine Valley, N. of Coniston. In a rock from the Long Sleddale Valley devitrification has resulted in the formation of small positive spherulites giving a well-defined black cross (see Plate XXXVIII.). This type of devitrification is associated with the more common micro-

(1) Analyses II. and III. are given in Mr. ALLPORT'S paper. They are quoted from ROTH'S Beiträge zur Petrographie, 1869, and Gesteins Analysen, 1861. The specific gravities of the rocks analysed are here added.

(2) SZABO. Der Granat und der Cordierit in den Trachyten Ungarns. N. J. Beilage Band I. 302.

(3) See also Q.J.G.S. Vol. XL. (1884), p. 344.

crystalline type. Rhyolitic (felsitic) tuffs are associated with the perlitic felsites at many points.

	I.	II.	III.
SiO_2 ...	67·180	69·044	67·180
Al_2O_3 ...	16·650	11·660	16·650
Fe_2O_3 ...	·559	2·030	·559
FeO ...	2·151	1·449	2·151
CaO ...	2·352	1·456	2·352
MgO ...	1·549	·540	1·549
K_2O ...	2·914	3·570	2·914
Na_2O ...	4·032	9·673	4·032
P_2O_5 ...	·179	tr.	·179
SO_3 ...	tr.	—	tr.
CO_2 ...	·885	tr.	·885
C ...	·797	—	—
H_2O ...	·752	·441	1·549
	100·000	99·863	100·000

I. Armboth dyke. Analysis by Hughes. Ward's memoir on the northern part of the Lake District.

II. Angitic granophyre from summit of Carrock Fell. Analysis by Hughes. Q.J.G.S., Vol. XXXII., p. 24. Also ·137 of Sulphur.

III. Quartz-felsite. Threlkeld. Q.J.G.S., Vol. XXXII., p. 22.

Cheviot District. Quartz-felsites are associated with the granite-mass of the Cheviots. They occur as dykes in the surrounding volcanic series. In colour they vary from pale red to dull purple. They are not conspicuously porphyritic, the individual crystals rarely exceeding a length of 2 mm. Examined with a hand lens the most conspicuous mineral is seen to be biotite which is evenly scattered through the rock in the form of hexagonal tablets. Crystals of felspar, usually of the same colour as the ground-mass, but occasionally weathering white, may be recognized. Grains of quartz are also seen to be present, but their importance as constituents of the rock is not recognized until the thin sections are examined. Under the microscope the porphyritic constituents are seen to present the usual characters. The boundaries of the mica are intact. The quartz occurs in bipyramidal crystals and in rounded or irregular grains. The ground-mass is micro- or cryptocrystalline. Traces of granophyric structure may occasionally be observed. Ill-defined specks, fibres and scales of ferrite are everywhere present and lie superposed even in the thinnest sections. As a rule these are irregularly scattered through the ground-mass, but in some instances they give rise to small spherical aggregates. In one case the ground-mass was seen to split up under crossed nicols into a coarse-grained aggregate. The boundaries of the double refracting grains are irregular and not recognizable in ordinary light. Each quartz-crystal in the rock formed the nucleus of one of these grains, so that the space surrounding it extinguished simultaneously with the crystal. A

specimen from a point on the Coquet, half-a-mile above Shillmoor Farm, was analysed by Mr. WALLER and yielded the following result :—

SiO_2	...	67·9
Al_2O_3	...	15·7
Fe_2O_3	...	3·0
CaO	...	1·4
MgO	...	1·5
Na_4O	...	1·5
K_2O	...	5·6
Loss	...	3·7
		100·3

Scotland.—Rocks of the group now under consideration abound in Scotland, but with the exception of those which occur in the island of Arran they have not as yet received much attention at the hands of modern petrographers. Intrusive felsites and quartz-porphyries are associated with the principal granite masses and form innumerable dykes in certain districts, especially in the Southern Uplands. Felsitic lavas and tuffs occur associated with the Old Red Sandstone and to a certain extent also with the Carboniferous rocks of the Midland Valley. They are again found in the Western Isles, where they belong to a much later geological period.

The microscopic characters of the felsitic and vitreous rocks of the Isle of Arran have been described by Professor ZIRKEL[1] and Mr. ALLPORT.[2] The pitchstones of Arran are also referred to by VOGELSANG.[3]

The felsitic rocks have at various times received such names as hornstone, claystone, claystone-porphyry, quartz-porphyry, felspar-porphyry, quartz-felsite and spherulitic felsite. The vitreous rocks have a resinous lustre and have always been known as pitchstone. Both varieties occur as intrusive sheets, dykes and more or less amorphous masses. They are of later date than the Carboniferous rocks of the Island.[4] In all probability they belong to the same period as the granites, granophyres and felsophyres of Mull and Skye.

The pitchstones of Arran are generally of a dark bottle-green colour. Some varieties are almost black. Porphyritic crystals of felspar and quartz may or may not occur. Globular spots of felsite occur in certain varieties. These may or may not show a radial structure.

Under the microscope the principal constituent is seen to be a nearly colourless isotropic glass, more or less charged with greenish acicular microlites. These microlites vary considerably in size. Sometimes they are so minute and so numerous as to give merely a dusty aspect to the section when viewed with a low power; at other times

(1) Z.D.G.G. (1871), p. 1.

(2) G.M., 1872, pp. 1-10 and 536-545; also G.M., 1881, p. 438.

(3) Die Krystalliten, p. 124.

(4) Professor ZIRKEL describes the pitchstone-sheet on the Corriegills shore as interbedded with the sandstones. Mr. ALLPORT has shown that this is not so. It is in reality intrusive.

they are so large as to show crystallographic outlines. The largest are, however, extremely small as compared with the porphyritic constituents occurring in the same rocks. Gradations in size may frequently be seen in one and the same slide (pitchstones of Corriegills shore and near Tormore on the west side of the Island) and when this is the case the larger microlites are aggregated together so as to form most exquisite arborescent groups. Some of these groups remind one of fir trees; others resemble, as Mr. ALLPORT has pointed out, the delicate sprays and tufts of Batrachospermum. These arborescent groups are always surrounded by a zone of clear glass; the interspaces between the zones being occupied by glass crowded with acicular microlites which can only be distinctly seen with a high magnifying power.

Various opinions have been held as to the nature of these microlites. Professor ZIRKEL referred to them as hornblende without however, giving any decided evidence as to their character. Mr. ALLPORT, having determined the existence of crystals of pyroxene in the rock, assumed in his earliest papers that the microlites were of the same nature. The pyroxenic nature of the microlites was believed in by VOGELSANG and is accepted by ROSENBUSCH in the last edition of his work on the massive rocks (p. 406). In 1881, however, Mr. ALLPORT showed conclusively that he had been mistaken in his original identification, and that Professor ZIRKEL had been right in regarding them as hornblende. Cross-sections of the larger prisms, which often form the central stems in the arborescent aggregates, give approximately the angle of hornblende (124° 30) and show only the form, 110 (see Fig. 4, Plate XXXIV.). The maximum extinction in the prismatic zone is 15°. There is another point about the large microlites, which may easily be observed, but which does not appear to have been recorded. They have in most, if not in all cases, a central core of glass and the form of the core is that of the hornblende prism—the core is in short a negative crystal. Very frequently the hornblende prism is imperfect in its periphery, a small portion being required to completely enclose the central core of glass. The ends of the minute prisms which show this structure are generally very ragged.

In a ground-mass of the above character we find porphyritic crystals and crystalline fragments of quartz, sanidine, plagioclase, pyroxene and magnetite. These porphyritic constituents sometimes occur in abundance, at other times they are entirely absent. The quartz occurs in corroded grains and bipyramidal crystals. The felspars are often completely honey-combed with inclusions. The inclusions, both in the quartz and in the felspar, often take the form of negative crystals. Thus, in quartz they are often seen to be hexagonal or rhomboidal, in felspar rectangular. The pyroxene occurs in grains and well-formed crystals. In some rocks the forms of the augites are

absolutely perfect, and, as the crystals are small, they may be well observed in thick sections of the rocks.

In some rocks the porphyritic constituents have exercised a marked influence on the arrangement of the microlitic groups; the latter forming a kind of fringe round the former. Certain dykes on the west coast show banded and fluxion structures.

Mr. ALLPORT has described the intimate relation between pitchstone and a variety of felsite known as "hornstone." These two rocks occur as modifications of one and the same mass in a vein on the west coast near King's Cove. The red hornstone differs from the pitchstone in being crypto-crystalline and in containing a large amount of colouring matter. It is interesting to note that the red colouring matter (ferrite) makes its appearance as soon as the matrix shows double refraction, that is as soon as crystallization takes place. This agrees with the views of VOGELSANG and ROSENBUSCH that it is squeezed out of the magma during the process of crystallization.

The felsites of Arran vary considerably in character. Some are compact and without porphyritic constituents; others contain crystals of bipyramidal quartz, sanidine and plagioclase; others again are markedly spherulitic; the spherules being sometimes as large as small peas and so thickly set as to make up the bulk of the rock. The ground-mass of the felsite varies in colour from a bluish black to light grey or yellow. Under the microscope it is crypto-crystalline, micro-crystalline, confusedly crystalline or spherulitic. Sometimes there are traces of granophyric structure. The small spherulitic bodies in the ground-mass of certain felsites are clear and radially fibrous. They give a well-defined black cross.

Fine examples of porphyritic felsites (liparites) occur at Drumadoon Point, Leac-a-Bhreac and Benan Head. The ground-mass is crypto- or micro-crystalline. The porphyritic constituents are quartz, often bipyramidal, sanidine, plagioclase. Microlites of hornblende occur in some varieties. As the porphyritic monoclinic felspar is usually clear and glassy these rocks would be liparites according to the nomenclature we have adopted. ZIRKEL calls attention to their close relation to the trachytes. The "claystones" of the earlier varieties occur abundantly as dykes They are less markedly porphyritic than the rock above referred to. Porphyritic grains of quartz frequently occur and they are usually surrounded by a zone which extinguishes simultaneously with the central grain. This is the "quartz globulaire" of French authors.

On the Corriegills shore there occurs a remarkable variety of spherulitic felsite, the microscopic structure of which has been described by Mr. ALLPORT (1) and Professor BONNEY.(2) The spherules are often as large as small peas (see Fig. 1, Plate XXXIX.). In thin section they show a radially fibrous, and frequently also a concentric structure, due to the distribution of brown granular matter. They do not show a well-defined

(1) G.M., 1872, p. 540.
(2) G.M., 1877, p. 499.

black cross in polarized light but consist of crystalline patches which give uniform extinction over considerable areas. These patches are, however, longer in the radial than in the tangential direction. Where the spherulites are closely set they mutually interfere, and divide up the mass into a polygonal net-work. The sutures appear as clear lines under the microscope.

	I.	II.	III.	IV.	V.	VI.
SiO_2 ...	72·50	66·03	72·6	73·90	78·05	78·32
Al_2O_3 ...	11·53	12·55	12·4	10·12	11·12	11·39
Fe_2O_3 } ...	2·06	2·75	·7	tr.	tr.	tr.
FeO }			1·1	1·23	1·08	1·67
MnO ...	—	—	—	1·19	0·15	—
CaO ...	1·79	2·80	·9	—	0·98	0·13
MgO ...	2·72	2·33	tr.	tr.	tr.	tr.
K_2O ...	5·24	4·13	4·7	2·42	tr.	0·20
Na_2O ...	3·37	5·02	1·7	2·64	4·94	7·62
H_2O ...	·70	4·20	5·2	8·23	3·58	1·47
	99·91	99·81	99·3	99·73	99·90	100·80
Sp. Gr. ...	—	—	2·340	—	—	—

I. "Claystone," Arran. Analysis by M. M. Tait. Quoted from Bryce's Geology of Arran, p. 203.

II. "Pitchstone," Arran. Analysis by same observer and quoted from the same source.

III. "Pitchstone," Arran. Analysis by J. H. Player. (Previously unpublished).

IV. "Hornstone" nodule in Pitchstone from vein occurring near King's Cove. Analysis by J. A. Phillips. G.M., 1872, p. 540.

V. Red felsite or "hornstone" from same locality. Analysis by J. A. Phillips. G.M., 1872, p. 540.

VI. Spherulitic or globular felsite. Corriegills shore, Arran. Analysis by J. A. Phillips. G.M., 1872, p. 540. See Fig. 1, Pl. XXXIX.

Felsitic lavas and tuffs are extensively developed in the Island of Mull. These have not, however, as yet been described in detail. The Scuir of Eigg is composed of a porphyritic pitchstone (see Fig. 5, Plate XXXIV.) in which crystals of quartz, sanidine, and augite occur It shows a well-marked perlitic structure, and in this respect differs from most of the Arran pitchstone. Arborescent microlites are absent. Rhyolites and felsites occur in the Shetland Isles, associated with Old Red Sandstone rocks. These have been described and figured by Messrs. Peach and Horne. (1)

Ireland.—The felsitic rocks of Ireland, like those of Scotland, have not received much attention at the hands of modern petrographers. One of the most interesting rocks is the tridymite-bearing liparite of Tardree,(2) Co. Antrim.

Macroscopically this rock consists of porphyritic crystals of glassy sanidine, plagioclase and smoky quartz in a pale yellow or white trachytic or felsitic matrix. The hollow spaces contain small hexagonal

(1) The Old Red Volcanic Rocks of Shetland. Trans. Roy. Soc., Edin. Vol. XXXII., Part II., p. 359.

(2) Lasaulx, T.M.M., Neue Folge. Band I. (1878), p. 410.

tablets of tridymite. Under the microscope biotite, magnetite, epidote and apatite may also be recognized as occurring in certain specimens of the rock. The ground-mass is crowded with minute grains of magnetite and indefinite granular matter. According to VON LASAULX it may be resolved, under a high power, into a confused aggregate of felspar-microlites and quartz-grains. Specimens examined by the author cannot be resolved. The matrix can only be described as crypto-crystalline. The large quartz grains show the corroded forms characteristic of the liparites and quartz-porphyries.

Cleavage flakes of the sanidine parallel to (010) give an extinction of 11° referred to the edge 010 : 001. The optic axial plane is at right angles to the plane of symmetry (orthose non déformé). The optic axial angle (in air) for red light was determined by VON LASAULX to be 28½°. Mr. DICK observed an angle of 46° in a specimen isolated by the author. The rock was analysed by Mr. HARDMAN,[1] but his analysis is so exceptional as regards the amount of alumina and lime that another analysis was kindly made for the author by Mr. PLAYER. It agrees with that of Mr. HARDMAN except as regards the alumina and lime.

		I.		II.
SiO_2	...	76·4	...	64·66
Al_2O_3	...	14·2	...	20·03
Fe_2O_3	...	1·6		
CaO	...	·6	...	1·21
MgO	...	—	...	—
K_2O	...	4·2	...	8·61
Na_2O	...	1·8	...	5·44
H_2O	...	1·5	...	—
		100·3		99·95

I. Liparite ; Tardree (PLAYER).
II. Sanidine from the liparite (Dr. BETTENDORF).[2]

Felsites and porphyritic felsites are associated with the Lower Palæozoic rocks of Wicklow and Waterford, and with the Old Red Sandstone rocks of Kerry. They are the silicco-felspathic rocks of Dr. HAUGHTON. Porphyritic constituents are not conspicuous in these rocks. They resemble the Ordovician felsites of Wales in structure and composition.

A banded spherulitic felsite occurs at Knockanduff, Co. Waterford. The spherulitic bodies may or may not show radial structure. In the

(1) Jour. Geol. Soc., Ireland, XIII., 29. Mr. HARDMAN's analysis is as follows :—
SiO_2, 76·960 ; Al_2O_3, 5·101 ; Fe_2O_3, 2·344 ; CaO, 7·064 ; MgO, 0·295 ; K_2O, 4·262 ; Na_2O, 1·818 ; H_2O, 2·102 ; P_2O_5, Trace.
It is interesting to observe that Mr. PLAYER's analysis agrees exactly with Mr. HARDMAN's so far as the alkalies are concerned.

(2) VON LASAULX. T.M.M., Neue Folge. Band I. (1878), p. 417.

latter case they give a well-defined black cross. The spherulites are sometimes arranged in bands. Spherulitic (nodular) felsites occur also in the Mangerton group and in Benaunmore (Kerry).

A typical "quartz-porphyry," that is a rock with conspicuous porphyritic crystals, is described by VON LASAULX, from Newcastle, Co. Down. Under the microscope hornblende and biotite may be recognized. The ground-mass is mainly composed of micro-pegmatite. This rock would be a typical granophyre in ROSENBUSCH'S sense.

A fine example of a biotite-quartz-felsite with indications of granophyric structure in the ground-mass occurs at Allthomasreagh, Co. Galway.

	I.	II.	III.	IV.
SiO_2 ...	81·36	78·40	77·20	71·52
Al_2O_3 ...	7·86	11·32	6·54	12·24
Fe_2O_3 ...	3·32	0·92	5·82	3·16
CaO ...	0·99	0·45	1·81	0·84
MgO ...	0·45	0·48	0·60	0·39
K_2O ...	3·09	4·83	3·69	5·65
Na_2O ...	2·63	3·09	3·03	3·36
Loss ...	—	·56	1·12	1·20
	99·70	100·05	99·81	98·36

I. Pale greyish green felsite. Bell Rock, Ovoca.

II. Similar rock showing in places minute felspar crystals—occasionally containing hollow nodules filled with quartz and chlorite (HAUGHTON). Carrickburn, Wexford.

III. Felsite, Bonmahon, Waterford.

IV. Benaunmore, Kerry. Containing small quartz and felspar crystals.

The above analyses were made by Dr. HAUGHTON.[1] They show a close relation between the Welsh and Irish felsites.

It is interesting to observe the occurrence in Ireland of nodular felsites similar to those described by Professor BONNEY and Mr. COLE.

(1) Trans. Roy. Irish Acad. Vol. XXIII. (1859), p. 615.

CHAPTER X.

Mica-Traps and Related Rocks.

In this chapter we shall refer to certain rocks of somewhat exceptional composition. These rocks do not fall readily into any scheme of classification based on Bunsen's law, as will be seen by an examination of the list of analyses quoted later on. In Britain they occur abundantly in two principal localities: in the Kendal and Sedbergh districts of Westmoreland and north-western Yorkshire and in the West of England, more especially Cornwall. The rocks of the former district have been described by Messrs. Bonney & Houghton[1]; those of the latter by Mr. Collins.[2] As matters stand at present there appears to be a difference in the age of the rocks in these two localities; those of the North of England occur as dykes in the lower Palæozoic rocks and are never known to enter Carboniferous strata; those of the West of England on the other hand occur in rocks as high as the Culm Measures.

The rocks in question always occur as dykes or veins which are often very narrow and difficult to trace for any considerable distance. They are generally much decomposed and frequently show a tendency to spheroidal weathering. Carbonates are generally present in considerable quantity. A brown mica is also usually present in considerable quantity and sometimes gives the rocks a decided porphyritic character. Felspar rarely occurs as a porphyritic constituent and in this respect these rocks differ from the porphyrites and porphyritic diorites. The investigation of these rocks is attended with great difficulty in consequence of the amount of alteration which has taken place. They are never found in a perfectly fresh condition. By selecting a number of the best preserved specimens it is possible to establish something like a classification of the group, but in working in the field rocks are frequently met with which it is impossible to refer to their proper position in such a classification. A vague term like trap or mica-trap is the only one that can be used in such cases. The following names have been applied to members of this group:—minette, kersantite, kersanton, lamprophyre, mica-diabase, minette-felsite, kersantite-porphyrite, mica-porphyrite, mica-diorite, mica-syenite. Rosenbusch has recently proposed two new names, vogesite and camptonite, for certain rocks allied to the mica-traps.

Minette. This is a local name used by miners in the Vosges for

(1) Q.J.G.S., Vol. XXXV. (1879), p. 165.
(2) Jour. Roy. Inst., Cornwall, Part II., Vol. VIII. (1884).

a rock essentially composed of dark mica, orthoclase and a felspathic matrix. It was introduced into geological literature by VOLTZ in 1828.

Kersanton (Kerzanton). This is the name of a small hamlet on the Brest Roads. It is locally applied to several varieties of rock, rich in plagioclase and dark mica and containing carbonates. These rocks are divided by M. BARROIS[1] into two groups : kersantites and mica-porphyrites (porphyrites micacées) ; the former being characterized by a granular, the latter by a porphyritic structure.

Kersantite. This term is sometimes used in M. BARROIS' sense and sometimes made to include both the granular and porphyritic rocks.

Lamprophyre. This name was introduced by GÜMBEL for certain rocks which occur as small dykes (usually running N. & S.) in the Palæozoic strata of the Fichtelgebirge, Thüringer Wald and Voigtland. They occur in strata as high as the Culm Measures. They bear a general resemblance to "diabase," but differ from that rock in containing a large amount of dark mica. GÜMBEL remarks that this name is intended to include rocks that have been variously referred to as "mica-diabase, minette, kersanton and kersantite." It is interesting to note that GÜMBEL's lamprophyres are similar in composition, state of preservation, geological age and mode of occurrence to the mica-traps of Cornwall and Devon. ROSENBUSCH has accepted GÜMBEL's term lamprophyre but has somewhat extended its signification. He applies it to rocks which occur as dykes in disturbed regions and which, so far as composition is concerned, have affinities on the one hand with syenites and on the other with diorites. They may be fine-grained, compact or porphyritic in structure. In the porphyritic varieties felspar rarely occurs in the form of large crystals. The porphyritic texture is due to one of the ferro-magnesian minerals. The frequent occurrence of carbonates is also mentioned by ROSENBUSCH as a characteristic.

The lamprophyre group is then divided by ROSENBUSCH as follows :—

SYENITIC LAMPROPHYRES.	DIORITIC LAMPROPHYRES.
Minette.	*Kersantite.*
Vogesite.	*Camptonite.*

In the syenitic lamprophyres orthoclase is the dominant felspar ; in the dioritic lamprophyres plagioclase is the dominant felspar. In minette and kersantite a dark mica is the dominant ferro-magnesian constituent ; in vogesite and camptonite either augite or hornblende is the dominant ferro-magnesian constituent. It thus appears that there is little or no mineralogical or textural difference between vogesite and syenite, or camptonite and diorite. The difference lies in the mode of occurrence. ROSENBUSCH does not refer to the occurrence of any amorphous interstitial matter in his lamprophyres. It seems clear, however, from the researches of BONNEY and others that amorphous matter is present in certain rocks which have precisely the same mode of occurrence as the lamprophyres of ROSENBUSCH. When the dominant felspar is orthoclase BONNEY calls

(1) Sur le Kerzanton de la Rade de Brest. Ann. d.l. Soc. Geol. du Nord (1886). T. XIV., p. 3.

such rocks minette-felsite; when the dominant felspar is plagioclase he uses the term kersantite-porphyrite. The determination of the presence of interstitial matter is rendered difficult by the fact that the felspars of the ground-mass have frequently lost all individual action on polarized light.

Mica-diabase. This term should be applied to altered plagioclase-augite rocks rich in brown mica. The augitic camptonites of ROSENBUSCH, in which mica plays an important part, might be termed mica-diabase.

Mica-diorites. This term might be used with appropriateness for the hornblendic camptonites of Professor ROSENBUSCH in which mica plays an important part.

Mica-syenite. This term is the equivalent of minette.

Minette-felsite, Kersantite-porphyrite. The sense in which those terms are used by Professor BONNEY has already been explained.

Mica-porphyrite. This term should only be applied to rocks in which felspar occurs as a porphyritic constituent. The typical mica-porphyrites belong to the intermediate group; not to the group under consideration.

CHARACTERS OF THE ROCK-FORMING MINERALS.

Mica.—This is the most important and characteristic mineral. It occurs in thin plates which are often extremely ragged at their edges. They frequently contain intrusions and inclusions (apparently) of the ground-mass. In colour they are a rich, but somewhat pale brown. Sections parallel to the vertical axis are dichroic but not so markedly so as in the mica of the granitites and quartz-diorites. When viewed with rays vibrating at right angles to the cleavage cracks such sections appear colourless in thin sections. Under crossed nicols they give vivid polarization tints, which, however, do not appear to be so high as those of muscovite. The central portions of the crystals are often lighter in colour than the marginal portions. They are biaxial with a small optic axial angle. The optic axial plane is sometimes parallel to two of the edges of the hexagon; sometimes at right angles to these edges. In other words the mineral sometimes belongs to the meroxene and lepidomelane group of micas, sometimes to the anomite group. The latter case was observed by Mr. DICK in the mica of the Roseash rock described by Mr. DOWNES.[1] The angle for blue rays was found to be about 7° in air, that for red rays was about 16°. The dispersion, therefore, was $\rho > \nu$.

Alteration sometimes appears to bleach the mica; at other times it converts it into chlorite. Calcite and epidote are frequently found in lenticles between the lamellæ of the more or less altered micas. This mica often shows lamellar twinning in sections at right angles to the principal cleavage.

Felspar.—The unstriated felspars occur in more or less idiomorphic crystals and irregular grains. In the former case they give lath-shaped sections which are usually only two or three times longer than broad. The dominant forms, according to ROSENBUSCH, are P (001), M (010) and

(1) Trans. Devon. Ass., Vol. XVI. (1884), p. 498-500.

y (201). When present in the form of irregular grains the unstriated felspars frequently constitute a kind of ground-mass in which the other constituents lie embedded. The striated felspars may occur in forms giving long lath-shaped sections, or short and broad sections in which the lath-shaped form is not so strongly marked. Where both striated and unstriated forms occur the former are usually idiomorphic with respect to the latter. In the kersantites of Brittany unstriated felspar and quartz are frequently intergrown so as to form micro-pegmatite. The bulk analyses of the rocks and micro-chemical reactions on the minerals themselves show that the felspars must be somewhat abnormal in composition. In many cases they probably belong to the anorthoclase group of ROSENBUSCH. As already stated the felspars have frequently lost their original characters by alteration, and a precise classification of the rocks is thus often rendered impossible. Cloudy granular matter, usually coloured red by iron-oxides, has been produced and the mass then gives only aggregate polarization. Calcite is also richly developed by the processes of decomposition.

Augite.—When fresh this mineral is almost always nearly colourless or a very pale green. It resembles the augite (malacolite) of the augite-granites and of the basic diorites of Warwickshire and Inchnadampf. According to ROSENBUSCH it frequently contains octahedra of chromite or picotite. By alteration it gives rise to chloritic or serpentinous substances. Sometimes it is changed to uralite.

Hornblende.—This mineral may occur, according to ROSENBUSCH, in short columns or in long prisms. It may be brown or green in colour. A blue variety (not glaucophane) has been observed in a minette from Wachenback in the Vosges. Zonal structure and twinning are common. The crystalline forms are those usually found in the rock forming hornblendes. Basaltic hornblende occurs in the camptonites of ROSENBUSCH. Alteration develops chloritic and serpentinous substances with which carbonates are frequently associated.

Accessory minerals.—Apatite plays a very important part as an accessory constituent. It is frequently present in extraordinary abundance (*e.g.*, augite-minette of Trelissick Creek, Cornwall), and it is often the only mineral which remains unaltered. Carbonates have already been referred to. They may occur in the form of crystalline powder irregularly diffused through the mass of the rock or as definite crystalline plates.

Olivine has frequently been observed in Continental minettes and kersantites. BECKE proposed the name of pilite-kersantite for a rock in which the pseudomorphs of olivine contained innumerable tremolite needles, somewhat similar to those which occur in the olivine-pseudomorphs of the Menheniot picrite. Iron-ores are present in almost all the rocks. Magnetite, ilmenite and hematite have been observed. Quartz is frequently present and appears to be both an original and a secondary constituent. The original quartz may occur as grains or as a constituent of micro-pegmatite. Secondary quartz occurs in irregular grains.

Description of the Rocks.

As already stated these rocks usually occur as small dykes or veins. They frequently show a tendency to spheroidal weathering. Sometimes the constituents of the rock, especially the felspar, show a tendency to radial grouping so that spheroidal structures (1 c.m. in diameter) may arise (kugelminette). This is often a contact phenomena. The mode of alteration, the abundance of brown mica in the typical rocks and the frequent presence of carbonates, when taken in connection with the mode of occurrence, are the most characteristic features of the group. It will be seen from the above descriptions that, like all other petrographical groups, it is very ill-defined. A rigid definition can only be given to the group by ignoring transitional forms, which after all are as abundant as the typical forms.

Kendal and Sedbergh Districts.—These rocks have been described by Messrs. Bonney and Houghton. They vary considerably in colour from pale grey to dark grey with reddish, brownish and purplish tints. Mica is abundant in most of them. The state of preservation often makes it difficult to speak positively as to the original character of the felspars and of the ground-mass. Microlites of felspar and augite occur in some of the ground-masses. Augite also occurs in definite crystals. In the rock of the highest dyke in Helm Gill Professor Bonney observed a fan-like grouping of the felspars. Biotite occurs not only in macroscopically-recognizable crystals but also as a constituent of the ground-mass in some of the porphyritic rocks. The authors classify the dykes as follows :—

Minette : Cross Haw Beck. Kersantite : Bed of Lune and Holbeck Gill. Micaceous Diorite : Gill Bank and Stile-End Farm. Minette-Felsite : Near Windermere Station ; Kendal Road ; Railway, Docker Garth ; South of Haygarth ; Helm Gill ; Backside Beck. Kersantite-Porphyrite : Uldale Head ; Wattle Gill ; Westerdale. Porphyrite : Barley Bridge.

The minette contains augite and is therefore an augite-minette. The micaceous diorites answer to Professor Rosenbusch's camptonites. The following analyses of these rocks are by Mr. Houghton :—

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2 ...	44·44	46·17	49·52	61·12	48·57	58·34	47·88	32·31
Al_2O_3 ...	17·85	16·95	17·97	15·99	18·52	16·33	19·14	12·15
Fe_2O_3 ...	4·82	5·46	5·06	0·84	1·60	2·28	4·33	1·97
FeO ...	3·62	0·83	2·61	1·70	6·87	3·88	1·67	5·99
MnO ...	tr.	0·10	0·40	tr.	0·60	0·14	0·35	0·13
CaO ...	7·54	10·23	7·80	5·12	2·79	5·65	6·16	17·68
MgO ...	7·57	7·13	6·17	4·93	8·97	3·34	6·36	8·24
K_2O ...	4·78	3·96	2·34	4·80	3·71	5·55	5·54	4·09
Na_2O ...	0·99	2·42	2·52	2·04	1·59	2·20	2·45	0·43
H_2O ...	2·59	2·87	3·52	2·21	3·83	2·35	3·01	3·69
CO_2 ...	6·39	4·84	1·16	1·83	tr.	0·66	2·01	13·13
	100·59	100·96	99·07	100·58	97·05	100·72	98·90	99·81

I. Minette-felsite: ¾ mile from Windermere Station.
II. Micaceous diorite: Gill Bank, 1¼ mile N.N.E. of Staveley.
III. Micaceous diorite: Stile-end Farm, about 5 miles N. of Staveley.
IV. Minette-felsite: Kendal Road, 250 yards from third milestone.
V. Minette-felsite: Railway, W. of Docker Garth.
VI. Minette-felsite: Docker Fell; S. of Haygarth.
VII. Minette-felsite: Docker Fell; S. of Haygarth.
VIII. Minette-felsite: Helm Gill, near Sedbergh.

West of England.—In his paper[1] on the "Rocks of the Mining Districts of Cornwall" Mr. J. A. PHILLIPS describes a remarkable "Elvan" from Trelissick Creek, north of Carrick Roads, near Falmouth. The width of this elvan, which penetrates a greyish slate, is about thirty feet. Its colour varies from yellow or buff to a dark chocolate brown, in accordance with the less or greater degree to which the iron present has become peroxidized. Its general appearance is that of a rock composed of a large quantity of mica, with a little felspar, enclosing occasional crystalline fragments of quartz. Under the microscope thin sections are seen to consist of a nearly equal mixture of quartz, felspar and brown mica enclosed in a felspathic base. The felspar is monoclinic. A section in the British Museum prepared from a rock from the same locality contains a nearly colourless augite in addition to the constituents mentioned by Mr. PHILLIPS. Apatite and octahedra of magnetite also occur. The rock is a typical augite-minette. Mr. PHILLIPS' analysis is quoted below.

It is to Mr. COLLINS that we are principally indebted for our knowledge of the mica-traps of Cornwall. In the paper already referred to he describes and records on a map thirty-five distinct outcrops of mica-trap in a band of country lying between Roscreage Beacon, three miles south of the Helford River and Watergate Bay, near New Quay, on the north coast of Cornwall. The individual dykes have, for the most part, a course about N.N.E., but they are often somewhat tortuous and frequently split up into branches, some of which have, for short distances, directions very different from that mentioned.

These dykes are evidently posterior to the main earth-movements that have affected the rocks. They are in no way related to the pre-granitic greenstones which they in some cases (*e.g.*, Towan Head, near New Quay) very closely resemble. It follows from the researches of Mr. COLLINS that these rocks are similar in composition, mode of occurrence, and geological age to the kersantites of Brittany[2] and the Hartz,[3] to the lamprophyres[4] (GÜMBEL) of the

(1) Q.J.G.S., Vol. XXXI. (1875), p. 337.

(2) M. BARROIS. Sur le Kerzanton de la Rade de Brest. An. d. l. Soc. Geol. du Nord. T. XIV., p. 31.

(3) K. A. LOSSEN. Über die Kersantite-Gänge des Mittelharzes. Jahr. d. k. k. preuss. geol. Landesanstalt für 1885. MAX KOCH. Die Kersantite des Unterharzes. Jahr. d. k. k. preuss geol. Landesanstalt für 1886.

(4) C. W. GÜMBEL. Die paläolithischen Eruptivgesteine des Fichtelgebirges. München, 1874.

Fichtelgebirge and with the kersantites and minettes[1] of South Thuringia and the Frankenwald.

The following analyses, with the exception of the first, were made by Mr. COLLINS.

	I.	II.	III.	IV.	V.	VI.	VII.	VII.	IX.	X.
SiO_2	47·35	48·75	48·40	60·60	50·10	57·06	55·45	53·90	51·75	53·30
Al_2O_3	20·60	22·99	15·93	17·99	19·45	21·51	25·95	21·92	23·58	24·18
Fe_2O_3	3·10	4·01	4·50	7·31	10·75	7·19	6·07	7·78	10·37	12·02
FeO	1·60	1·55	1·98							
CaO	4·72	4·37	6·83	2·41	4·03	1·10	1·26	0·48	2·46	0·73
MgO	6·12	5·62	4·36	1·37	5·13	4·18	2·39	5·29	3·03	3·75
K_2O	6·29	1·10	0·94	3·80	1·60	0·26	1·48	0·67	tr.	tr.
Na_2O	3·58	5·97	2·10	2·38	3·90	3·73	4·30	5·54	2·55	1·27
CO_2	—	3·43	9·17	—	2·00	—	—	0·10	—	—
H_2O	6·45	2·40	5·80	3·20	1·42	4·64	2·85	3·60	5·50	4·70
	99·81	100·19	100·01	99·06	98·38	99·67	99·75	99·28	99·24	100·25
Sp. Gr.	2·70	2·73	2·75	2·50	2·75	2·46	2·66	. .	2·54	2·72

I. Augite-minette. Trelissick Creek. Analysis by Mr. PHILLIPS.
II. Lamb Creek, near Truro.
III. Nare Point, near Porthalla.
IV. Nare Point, near Porthalla. This is stated by Mr. COLLINS to be part of the same mass as that which yielded Analysis III.
V. New Quay. Contains ·32 of P_2O_5.
VI. Fiddler's Green Dyke.
VII. Flushing.
VIII. The Gannel. Contains ·20 of P_2O_5.
IX. Roscreage, near the foot of the Beacon.
X. Beacon Hill, Falmouth.

The first three analyses represent the composition of the normal mica-traps; the remaining analyses were made from weathered specimens. Mr. COLLINS states that all the rocks contain phosphoric acid, manganese, lithia and fluorine. Speaking of their physical characters, he says:—"The rocks vary in colour from golden yellow to greyish or chocolate brown, with often a purplish tinge in the hardest parts when freshly broken. Near the surface they are often much decomposed. . . . . When the rock is undecomposed its appearance is unmistakable, whether fine or coarse grained; where the decomposition is but slight, it often simulates to a cursory view a brown sandstone, for which, locally, it is often mistaken. . . . . A tendency to spheroidal structure developed by decomposition may generally be observed."

The author is indebted to Mr. COLLINS for a specimen from the Helford River. It is a medium-grained rock in which the two principal constituents, a dark mica and a pink felspar, can be easily recognized with a lens. The examination of a thin section shows that the matrix of the rock in which the other constituents are embedded is a coarse-grained aggregate of unstriated felspar. Notwithstanding the presence of considerable quantities of ferrite and calcite-dust the grains retain

(1) R. PÖHLMANN. Über Glimmer-diorite und Kersantite Südthuringens und des Frankenwaldes. N. J. Beilage Band III. (1885), p. 67.

a sufficient amount of individuality to enable their outlines and internal structure to be made out. They show no trace of crystalline form, the irregular grains fitting together so as to make up the matrix in which the other constituents—brown mica, apatite and magnetite—are embedded.

The mica occurs in thin plates, the edges of which are extremely irregular, but with indications of the crystalline faces. The margin is always darker than the central portion. The optic axial plane lies parallel to the plane of symmetry and the plates are sometimes elongated in this direction—not regularly hexagonal. The more or less lath-shaped sections often show under crossed nicols a lamellar twinning. Adjacent lamellæ extinguish in different positions; the angle between the two positions being about 6°. This shows that the first mean line (negative bisectrix) is inclined to the basal plane which is the face of composition. The lath-shaped sections show the usual dichroism. They become colourless when viewed with rays vibrating at right angles to the cleavage cracks. The plates of mica have frequently suffered mechanical deformation. They sometimes contain lenticles of calcite. Apatite is very abundant. It occurs in well-crystallized prisms with pyramidal terminations and often shows cross jointing at irregular intervals. Magnetite is present in well-crystallized octahedra. There are some quartz grains which may be of secondary origin. Calcite-dust is distributed in patches through the felspar, and there is also some calcite which is definitely crystalline. The rock is a minette. It closely resembles the Trelissick rock analyzed by Mr. PHILLIPS. Augite cannot however, be recognized with certainty, although there are some green patches which may represent this mineral.

Other localities. Mica-traps occur in the Channel Islands. Two of the Guernsey dykes are described by Professor BONNEY in an appendix to a paper by Mr. HILL.[1] That of Moulin Huet contains a trachytic ground-mass mainly composed of elongated felspar microlites. It is a kersantite-porphyrite. The rock of Bec du Nez is less markedly trachytic in texture and is therefore more allied to kersantite. Allied rocks are described by M. NOURY[2] from Jersey under the name of micaceous porphyrite.

The mica-traps of the Channel Islands doubtless belong to the same period as those of Cornwall, Brittany, the Hartz and the Fichtelgebirge.

Mr. WARD[3] describes a minette from Sale Fell, west of Bassenthwaite Lake in Cumberland. Professor HULL[4] states that mica-traps occur as "dykes or beds amongst the Silurian rocks of Wicklow, Cavan, Monaghan and Down; also in Co. Wicklow and other parts of Ireland, as near Louisberg, Co. Mayo. In Scotland also they are found amongst the Silurian rocks of the Southern Uplands, apparently continuous with those of the North of Ireland."

(1) Q.J.G.S., Vol. XL. (1884), p. 426.
(2) Géologie de Jersey. Paris, 1886.
(3) Survey memoir on the northern part of the Lake District, p. 33.
(4) On Building and Ornamental stones. London, 1872, p. 83.

CHAPTER XI.

GROUP D.

Nomenclature.

THE only indigenous rock belonging to this group, known to occur in Britain, is the phonolite of the Wolf Rock, described by Mr. Allport in 1871.[1] Boulders of zircon-syenite (elæolite-syenite) are said to occur in the drifts of East Anglia, but the author is unable to say whether the identification has been made with certainty. Seeing that the group is so poorly represented in Britain it is unnecessary that any detailed description should be given of it in a work like the present. With a view, however, to future eventualities we will give a brief account of its nomenclature and of some of the more important minerals which characterize it. The names zircon-syenite, elæolite-syenite nepheline-syenite, foyaite, miascite, ditroite, teschenite and theralite have been applied to the plutonic representatives of the group, and the names phonolite, tephrite, leucitite, nephelinite, liebenerite-porphyry, gieseckite-porphyry, buchonite, leucite-basalt, nepheline-basalt and basanite to the volcanic representatives.

Zircon-Syenite.—This is an old name introduced by Hausmann[2] for certain rocks occurring in Southern Norway. It has since been shown that zircon is an accessory mineral, and although very abundant in certain specimens is comparatively rare in others from the same general mass. The name has accordingly been dropped in favour of others, such as augite-syenite and elæolite-syenite, which express more accurately the composition of the rocks.[3]

Elæolite- or Nepheline-Syenite.—The former term is used by Rosenbusch, the latter by Brögger and some other authors. Elæolite-syenite, according to Rosenbusch, includes all those plutonic rocks which are characterized by the occurrence of orthoclase and elæolite. These two minerals are present in very different proportions in different occurrences, and even in one and the same rock-mass. The ferro-magnesian con-

(1) G.M., 1871, p. 247, and 1874, p. 462.

(2) N.J., 1852, p. 712.

(3) See Brögger, Die silurischen Etagen 2 and 3.

stituents include several varieties of pyroxene, hornblende and biotite. The typical rocks of the group are thoroughly granitic in texture, but there are transitional forms which connect the elæolite-syenites with the phonolites. Miascite, foyaite and ditroite are merely varieties of elæolite-syenite. The group is exceptionally rich in accessory minerals. Minerals containing the rare elements, thorium, yttrium, cerium, lanthanum, didymium, niobium, &c., occur in veins in these rocks.

Foyaite.—Term applied by BLUM to a rock occurring in the mountains of Monchique in Southern Portugal. This rock was defined by him as a crystalline granular compound of orthoclase, elæolite and hornblende. WERVEKE[1] has shown that the dominant ferro-magnesian mineral is augite and not hornblende. The latter mineral does, however, occur. Some authors use the term foyaite as synonymous with elæolite-syenite.

Miascite.—Term introduced by G. ROSE for a rock occurring in the Ilmen Mountains in Russia, essentially composed of orthoclase, elæolite and dark mica.

Ditroite.—Term applied to a rock occurring at Ditró (Hungary), essentially composed of orthoclase, elæolite, cancrinite and blue sodalite (chlor-hauyn). Hornblende and ægirine are present, but do not enter largely into its composition. A characteristic feature of the typical ditroite is the abundance of brilliant blue sodalite. Ditroite may, therefore, be described as a variety of elæolite-syenite exceptionally rich in sodalite.

Teschenite.—This name was introduced by HOHENEGGER for certain rocks which are intrusive in the Cretaceous strata of Silesia and Moravia. The rocks in question were subdivided by TSCHERMAK into two groups —picrites and teschenites. The teschenite of TSCHERMAK[2] is a crystalline granular rock, composed of felspar, hornblende, augite and analcime; with magnetite, biotite, apatite, natrolite and apophyllite in smaller quantities. ZIRKEL and ROSENBUSCH have both recorded the occurrence of nepheline in this rock. TSCHERMAK[3] described a rock from the Caucasus under the name teschenite, and mentioned the existence of nepheline in this rock. MACPHERSON[4] described a rock from Cezimbra (Portugal) as teschenite, and also recorded the occurrence of nepheline. According to ROHRBACH, however, all these authors have been mistaken as to the existence of nepheline,[5] so that at present it is doubtful whether the teschenites should be classed with the nepheline-bearing rocks or not.

Theralite.—This term has been proposed by ROSENBUSCH for plutonic rocks characterized by the occurrence of plagioclase and nepheline. The

(1) N.J., 1880, Band II., p. 141.

(2) Die Porphyrgesteine Österreichs. Wien, 1869, p. 258.

(3) T.M.M., 1872, p. 107.

(4) B.S.G.F., 3rd Se. T. X. (1882), p. 289.

(5) T.M.M., Band VII., 1886, p. 29.

group is represented, according to ROSENBUSCH, by certain rocks from Montana, U.S.A., described by WOLFF,(1) and also by those teschenites (if any) which contain or contained nepheline.

Phonolite.—Term proposed by KLAPROTH in place of the old term clinkstone. As used now it generally implies a trachytic texture and the occurrence of sanidine and either nepheline or leucite or both. Many authors restrict it to rocks containing nepheline and sanidine. ROSENBUSCH, however, includes certain rocks without nepheline but containing leucite (*e.g.*, leucitophyres and leucite-trachytes). There are many varieties of phonolite depending on the accessory minerals. These have received such names as leucite-phonolite, nosean-phonolite, leucite-nosean-phonolite, &c.

Tephrite.—This term is used by ROSENBUSCH for the trachytic representatives of the theralites. The tephrites, therefore, are characterized, according to this author, by the occurrence of plagioclase and either nepheline or leucite or both. The two principal groups are the nepheline-tephrites and the leucite-tephrites.

Leucitite.—This term is generally used to designate a trachytic rock in which leucite takes the place of felspar, and from which olivine is absent. The olivine-bearing rocks of similar character are termed *leucite-basalts.*

Nephelinite.—This term corresponds to the preceding with the difference that it is applied to rocks in which nepheline takes the place of felspar. The olivine-bearing rocks are termed nepheline-basalts.

Liebenerite-porphyry.—This term is applied to a rock occurring in the Southern Tyrol. The rock is of trachytic texture and may be described as an altered phonolite. It contains porphyritic crystals of orthoclase and liebenerite (pseudomorph after nepheline) in a compact ground-mass. A similar rock from Greenland has been termed gieseckite-porphyry. Gieseckite and liebenerite appear to be synonyms.

Buchonite. This term was proposed by SANDBERGER for a rock occurring in the Rhöngebirge (North Germany). The rock is composed essentially of nepheline, plagioclase, augite and magnetite and is therefore a nepheline-tephrite.

Basanite. This term is used by some authors to include the nepheline- and leucite-basalts.

The rocks of the present group belong to the intermediate and basic divisions so far as silica percentage is concerned. They differ, however, from the ordinary intermediate and basic rocks in containing a very

(1) Notes on the petrography of the Crazy Mountains, &c. Northern Transcontinental Survey. See also N.J. Ref., 1886, Band I., p. 268.

high percentage of alkalies. Owing to the fact that many of the constituent minerals—nepheline, leucite, nosean, sodalite, melilite, &c.—are decomposed by hydrochloric acid it follows that a large proportion (often as much as 50 per cent.) of any rock belonging to this group is soluble in this acid. The following analyses will give an idea of the composition of different members of the group.

	I.	II.	III.	IV.	V.
SiO_2	54·61	61·06	55·76	56·09	47·44
Al_2O_3	22·07	19·06	21·61	22·22	23·71
Fe_2O_3	2·33	2·94	1·65	4·08	6·83
Fe(Mn)O	2·50	—	4·09	—	3·53
CaO	2·51	1·09	2·26	0·69	6·47
MgO	0·88	0·71	0·74	tr.	1·95
Na_2O	7·58	5·35	6·94	9·16	6·40
K_2O	5·46	6·83	5·34	7·21	3·34
H_2O	1·13	3·54	3·49	1·09	1·73
TiO_2	0·09	—	—	—	—
P_2O_5	0·15	—	—	—	—
	99·31	100·58	101·88	100·54	101·40
Sp. Gr.		2·638			

I. Elæolite-syenite, Caldas de Monchique, province of Algarve, S. Portugal (quoted from Merian N.J. Beilage Band III., p. 271.)

II. Phonolite, La Tuillière, Mont Dore (Rammelsberg) quoted from Roth, Beiträge zur Petrographie (1869).

III. Elæolite-syenite (Foyaite). S. Vincent, Cape Verde Islands. Doelter. Die Vulkane der Capverden. Graz (1882), p, 76.

IV. Phonolite. S. Antao. Cape Verde Islands. Doelter *loc. cit.*, p. 93. Contains traces of SO_3.

V. Nepheline-tephrite. S. Antao. Analysis by Kertscher. Quoted from the above-mentioned work by Doelter, p. 99.

	VI.	VII.	VIII.	IX.	X.
SiO_2	48·80	48·59	45·03	44·35	45·24
Al_2O_3	16·83	19·58	11·35	10·20	19·22
Fe_2O_3	—	4·38	13·91	13·50	5·21
Fe(Mn)O	6·60	4·56	4·89		5·69
CaO	6·50	9·12	7·86	11·47	9·18
MgO	1·24	3·12	4·61	12·31	6·71
Na_2O	9·52	2·15	7·86	3·37	3·37
K_2O	6·59	6·27	2·93	4·42	1·31
H_2O	1·96	0·12	1·51	—	3·78
TiO_2	—	—	—	—	—
P_2O_5	—	2·04	0·12	—	—
	98·04	99·93	100·07	99·62	99·71

VI. Leucitophyre (leucitite with porphyritic crystals) Rieden. Eifel. Quoted from Merian's paper, p. 276. Contains also SO_3 1·70 and Cl. 0·26.

VII. Leucitophyre. Vesuvius. Lava of March 3, 1881. Contains also SO_3 0·15 and traces of Cl. and Cr_2O_3. Ricciardi. Quoted from Roth. Beiträge zur Petrographie, 1884.

VIII. Nephelinite, Katzenbuckel, Odenwald. H. Rosenbusch. Inaug. Diss. Freiburg 1869. p. 39. Contains also nickel and cobalt.

IX. Leucite-basalt. Bongsberg near Pelm, Eifel. Hussak. Quoted from Roth, 1879.

X. Nepheline-basalt. Naurode near Weisbaden. Sandberger. Quoted from Roth, 1884.

Leucite and nepheline-bearing rocks are not so common as felspar-bearing rocks. Elæolite-syenites occur in southern Norway, in South Greenland (eudialyte-bearing elæolite-syenite), in the Portuguese Province of Algarve, at Ditró in Hungary, at Miask in the Ilmen mountains of Russia, in the north-west of New Jersey, at Lichfield in Maine, in the Cape Verde Islands, off the west coast of Senegambia (Los Islands and the island of Tumbo) and in Brazil. Phonolite is recorded from Saxony, Bohemia, the Eifel, the Westerwald, South Thuringia, the Vogelsgebirge, the Rhöngebirge, the Kaiserstuhl and Hegau in Baden, Auvergne, Sardinia, Tripoli, Kordofan, Cape Verde and Canary Islands, Aden, Fernando Noronha and the mainland of Brazil. The phonolite of the Wolf rock has already been mentioned.

Leucite rocks occur in the Eifel, in the neighbourhood of the Laacher Lee, in the Westerwald, Westphalia, the Vogelsgebirge, Baden (Kaiserstuhl), Saxony, Bohemia, Scania (S. Sweden), Italy (including the lavas of Vesuvius and Monte Somma), Sardinia, Cape Verde Islands, north-west Persia, Java, and Wyoming in U.S.A. Nepheline rocks, other than phonolites, occur in the Eifel, the Westerwald, the Taunus, Hesse, the Odenwald, Baden, the Rauhe Alp, the Vogelsgebirge, the Rhöngebirge, Thuringia, the Fichtelgebirge, Saxony, Bohemia, Silesia, Spain, South Greenland, South Sweden, the Cape Verde and Canary Islands, Montana U.S.A. and the Sandwich Islands. It will be observed that the leucite and nepheline rocks generally hang together so far as distribution is concerned.

Description of the Minerals.

Orthoclase.—The orthoclase of the elæolite-syenites generally occurs in allotriomorphic grains of nearly equal dimensions in the different directions. When, as sometimes happens, the elæolite-syenite assumes more or less the structure of a phonolite the orthoclase may become tabular in consequence of the development of the clino-pinacoid. In the elæolite-syenites of southern Norway the orthoclase is rich in soda (soda-orthoclase of Brögger) and often becomes idiomorphic with development of the forms T, l and y. Felspars of this form are characterized by frequently giving rhombic sections. The orthoclase often shows micro-perthitic intergrowths with a triclinic felspar.

In the rocks with trachytic texture (phonolites) the orthoclase is present in the form of sanidine. It occurs as porphyritic crystals and frequently also as a constituent of the ground-mass. The crystals are usually columnar in form and elongated in the direction of the clino-diagonal axis. Twinning on the Carlsbad plan is sometimes present, but does not appear to be so common as in the sanidine-trachytes and granites. The columnar crystals of sanidine are frequently arranged in a parallel manner in the rock, and when this is the case the mass possesses a marked fissility.

It is sometimes difficult to distinguish between the small sanidines of the ground-mass and nepheline. The best way of discriminating

between these two minerals is to etch the slide with acid in the manner to be presently described.

Plagioclase.—In the elæolite-syenites of Norway this mineral is rare. In other rocks of the same general character it is more abundant. It shows extremely fine twin-striation and appears to be allied to oligoclase or albite. Basic felspars are not known in these rocks. The plagioclase of the other rocks belonging to the group now under consideration calls for no special description.

Elæolite and Nepheline.—The only distinction between these two minerals depends upon their mode of occurrence and general aspect. Elæolite is characteristic of the plutonic rocks and possesses a dull lustre. It is also often somewhat coloured (greenish, brownish or grey). Nepheline is characteristic of the volcanic rocks and possesses a glassy lustre. In the elæolite-syenites the elæolite often occurs in irregular grains. When crystalline form is developed the faces are the same as those of nepheline. By alteration it gives rise to zeolites, such as anaclime and thomsonite, or to cancrinite. The optical characters of elæolite are the same as those of nepheline. Nepheline is especially characteristic of the trachytic rocks. Idiomorphic crystals show the faces of the prism $(10\bar{1}0)$ and basal plane (0001); less frequent also those of the pyramid $(10\bar{1}1)$. Sections at right angles to the morphological axis are hexagonal, those parallel to this axis are rectangular or lath-shaped. When the pyramid is present the right-angles are truncated. The thickness of the crystal measured at right-angles to the morphological axis is generally equal to or greater than the thickness measured in the direction of this axis. Thus in the lath-shaped sections the short side lies parallel to the principal axis. This fact must be borne in mind in determining the character of the double-refraction of a doubtful mineral by observation with the quartz-wedge. The refraction and double-refraction are both low. In sections of the ordinary thickness nepheline gives the grey-blue and white tints of the first-order. Sections at right-angles to the optic axis give, in convergent polarized light, a broad indistinct cross in consequence of the low double-refraction of the mineral. As a general rule nepheline does not occur in large porphyritic crystals but only as a constituent of the ground-mass. Its recognition is often attended with great difficulty: especially when, as sometimes happens, it plays the rôle of ground-mass and does not show definite form. To make sure of nepheline and to separate it from other minerals it is frequently necessary to treat the slide with acid. (1) Nepheline may

(1) This should be done as follows:—Uncover a portion of the section and remove the canada-balsam with alcohol. Place a drop of hydrochloric acid on the uncovered section and spread it evenly over the slide; heat gently. Wash off the acid and then place on the slide a solution of fuchsin or some other material suitable for staining gelatinous silica. Wash with water and observe under the microscope. If everything has gone well the nepheline, and other minerals decomposable with separation of gelatinous silica, will be distinctly recognizable by the distribution of the staining substance. If the appearance after one treatment is unsatisfactory the process must be repeated. If too thick a coating of acid be used the gelatinous silica will spread out over the minerals not affected, and the result will be unsatisfactory.

be readily distinguished from apatite by treating the slide with nitric acid and adding a solution of ammonium molybdate. If the doubtful mineral be apatite the characteristic yellow precipitate will be formed.

Sodalite group.—Minerals of the sodalite group are very common in certain rocks containing nepheline and leucite. The three typical molecules in this group are represented by the following formulæ. Sodalite, $2(Na_2O\ Al_2O_3\ 2\ SiO_2) + NaCl$; Nosean, $2(Na_2O\ Al_2O_3\ 2\ SiO_2) + Na_2OSO_3$; Hauyn, $2(Na_2O\ Al_2O_3\ 2\ SiO_2) + CaOSO_3$. The minerals are rarely if ever found in an ideal state of purity in consequence of the fact that the typical molecules are capable of replacing each other. They crystallize in the cubic system, and the rhombic dodecahedron is the dominant form. The faces of the cube and octahedron may, however, be occasionally observed in combination with those of the dominant form.

Sodalite occurs abundantly in the elæolite-syenites. It may be present as irregular grains or more or less idiomorphic crystals. It is colourless or grey and often possesses a greasy lustre. WERVEKE found both sodalite and nosean in the elæolite-syenite of Southern Portugal, the two minerals being intergrown so that the former surrounded a kernel of the latter. Sodalite is readily etched by hydrochloric acid in the thin section, and crystals of common salt are formed as the acid evaporates. The refractive index of the mineral is low and it is of course isotropic. Sections of sodalite may be distinguished from basal sections of nepheline by the fact that the latter give a broad cross in convergent light. The most perfect crystals of sodalite are found in certain trachytes and phonolites.

Hauyn.—In consequence of the difficulty of distinguishing between hauyn and nosean (in the absence of the blue colour which sometimes characterizes the former) it is convenient to have one name to include both minerals. ROSENBUSCH uses hauyn as the group name. The common form of hauyn is the rhombic dodecahedron. The usual sections are therefore hexagonal or rectangular. The mineral is isotropic or shows only anomalous double-refraction. The inclusions are often highly characteristic. They may be distributed irregularly through the substance of the mineral or they may be heaped up, either in the centre or at the periphery, thus producing a zonal structure. Sometimes they are arranged in lines parallel to the crystallographic axes. The crystals of nosean in the leucitophyres of the Eifel district are usually surrounded by a narrow opaque border. Sometimes crystals of a mineral of the hauyn group are so abundant as to form an essential part of the rock-mass. When this is the case the rocks are termed hauynophyres.

Hauyn and nosean are easily decomposed by acid. If a slide containing either of these minerals be etched with acid then, if the mineral be hauyn, minute crystals of gypsum will be formed in abundance as the acid evaporates;[1] if, on the other hand, the

(1) If strong acid and a high temperature be employed cube-like crystals of anhydrite will form instead of gypsum (SAUER).

mineral be nosean such crystals will not be formed at all or only to a very small extent.

Augite.—Several varieties of augite occur in this group. The augite of the more basic members does not call for any special description. It is worthy of note, however, that idiomorphic augite in the form of large porphyritic crystals, and also in the form of small microlites, is far more common in the nepheline- and leucite- than in the felspar-bearing rocks. In the normal elæolite-syenites and in the phonolites and leucitophyres green augites are very common. These are in many cases ægirine. The brown alkali-bearing augite (akmite) also occurs. The optical properties of ægirine and akmite are markedly different from those of ordinary augite. The mineral is usually elongated in the direction of the vertical axis. The forms in the prismatic zone are (110) and (100). The negative bisectrix makes an angle of only 4° or 5° with the vertical axis. The extinctions, therefore, in the prismatic zone are always very low—even lower than in the hornblendes. Notwithstanding the fact of these low extinctions it is always perfectly easy to distinguish between ægirine and hornblende, for in the former the major axis of depolarization is the one which most nearly coincides with the vertical axis whereas in the latter it is the minor axis of depolarization which is most nearly coincident with this axis. The green microlites in the phonolite of the Wolf rock may thus be proved to be ægirine and not hornblende. Both akmite and ægirine are pleochroic. There are probably intermediate forms between typical akmite or ægirine and typical augite. The analyses made by MANN [1] are particularly interesting from this point of view. This observer separated the pyroxene from several rocks belonging to the present group and showed that the maximum extinction angle in the prismatic zone decreased as the percentage of iron and alkali increased.

	Total Iron as Fe_2O_3	Total Alkalies.	Extinction Angle.
Hauynophyre (Melfi) ...	12·67	1·99	39°
Leucitophyre (Rieden) ...	19·52	3·35	30°
Phonolite (Elfdalen) ...	22·44	9·36	12°
Phonolite (Hohentwiel)	26·35	13·33	10°

Hornblende.—This mineral appears to be less common than was formerly supposed. It does, however, occur. It is often green in colour. The alkali-hornblende, arfvedsonite, is present in the elæolite-syenites. In thin section it is extraordinarily pleochroic, varying from clear yellow to dark brownish black. Sometimes greenish tints may be observed. The extinction in the prismatic zone is not much less than 15°.

(1) N.J. (1884). Band II., p. 205.

Leucite.—This mineral occurs crystallized in icositetrahedra. It is found in the leucitophyres, leucite-tephrites, leucitites and leucite-basalts. The angles are often somewhat rounded. The smaller crystals appear thoroughly isotropic; the larger ones often show anomalous double-refraction. This double-refraction disappears when the crystal is heated to a certain point. The inclusions in leucite are often arranged in a zonal manner, and this feature becomes of importance in examining the basaltic rocks in which the mineral often occurs without any definite external form. Leucite in thin section is only slightly affected by hot acid. When it is so affected the silica separates in a pulverulent condition.

Melilite.—This mineral is frequently associated with nepheline and leucite. It may occur as more or less idiomorphic crystals or as irregular grains. The common forms are the prism (110) and basal plane (001); sometimes the vertical pinacoids are also developed. The crystals are usually tabular. Sections parallel to the vertical axis are therefore lath-shaped, the short side corresponding to the vertical axis; sections at right angles to the vertical axis are quadratic or octagonal. In many rocks the external form of the melilite is very imperfect, although it approximates to that of the typical crystal. The refraction is somewhat higher than quartz; the double-refraction is very low, the highest tint in ordinary sections being the grey-blue of the first order. Its character is negative, so that in the lath-shaped sections the major axis of depolarization is at right angles to the length of the section. STELZNER has shown that melilite very commonly possesses a highly characteristic micro-structure. The lath-shaped sections are often crossed transversely by a fine striation or else peculiarly-shaped structures, resembling pegs, spears or spatulæ, run out from the basal planes towards the centre of the section for a greater or less distance. This he terms "pflock-structure."

Melilite is essentially a basic silicate of lime and alumina. It is colourless or brown in thin sections and is very easily acted upon by hydrochloric acid in thin section. By the addition of a little sulphuric acid to the solution gypsum crystals are formed as the liquid evaporates.

Melanite.—This is a lime-iron-garnet. It occurs in idiomorphic crystals which show the forms (110) and (211) according to ROSENBUSCH. It is an accessory mineral very common in some of the leucite- and nepheline-bearing rocks.

Perowskite, $CaO\ TiO_2$.—This is an important accessory in certain rocks of the group now under consideration, especially those rich in melilite. It occurs in minute well-formed octahedra which often show anomalous double-refraction. The refraction is very high. By transmitted light the mineral appears greyish-white, violet-grey, greyish, brown, brownish-yellow to reddish-brown (ROSENBUSCH). It may easily be mistaken for one of the spinels. In doubtful cases a determination can only be effected by isolating the mineral and testing for titanic acid.

Black mica, iron-ores, olivine, apatite, zircon, titanite and other minerals occur in the leucite- and nepheline-bearing rocks, but they call for no special description.

Description of the Rocks.

The Wolf rock lies about nine miles south-east of the Land's End, and is covered by the sea at high water. At low water spring tides it measures only 175 feet by 150 feet and stands 17 feet above the sea. At high water it is 2 feet below the level of the sea. The fresh rock consists of a compact grey ground-mass through which porphyritic crystals of a glassy felspar are thickly scattered. Small black specks (nosean) may be recognized with a hand-lens. The rock is markedly fissile in one direction, but breaks irregularly and with difficulty in other directions (Allport). In thin sections the porphyritic constituents are seen to comprise sanidine and nosean; the ground-mass is holo-crystalline and consists of sanidine, nepheline, a few small crystals of nosean and ægirine. Iron ores are very scarce.

A few of the larger crystals of felspar are tabular but the majority are columnar. The columnar crystals give rectangular or lath-shaped sections; the former extinguish parallel to their edges and the latter give straight extinction or else very low (maximum 4° or 5°) extinction angles. As a rule twinning is absent; a few binary twins may, however, be recognized. Cleavage flakes parallel to M (010) give an extinction of about 5° referred to the trace of the P (001) cleavage. These facts show that the crystals are sanidine, and that the columnar form is due to elongation in the direction of the edge P/M. The extinction in the lath-shaped sections varies from 0° to 5°, and the majority give approximately straight extinction. Inclusions of nosean are common in the sanidines. The sanidine of the ground-mass occurs only in the form of columns.

Nosean occurs in idiomorphic crystals, which very commonly give hexagonal outlines. The smaller crystals are somewhat cloudy or dusty in appearance; the larger crystals frequently contain the characteristic black inclusions, which are either distributed irregularly or arranged in lines. The central part of a crystal often contains inclusions while the marginal part is free from them, the planes of separation being perfectly sharp and corresponding to the faces of the crystal.

Nepheline occurs as a constituent of the ground-mass. Cross-sections are hexagonal in outline, often with the angles somewhat rounded, and they of course appear dark in all positions under crossed nicols. Sections parallel to the morphological axis are rectangular and often nearly square. They polarize only in neutral tints and extinguish parallel to the bounding edges. In the fresh rock the nepheline appears to be always water-clear. A careful adjustment of the light is necessary to distinguish the outlines of the mineral, and to make out its precise distribution it is necessary to etch the slide with acid and stain with fuchsin or some other colouring matter.

The only other constituent of the rock which calls for description occurs in the form of small green microlites, which are generally five or six times longer than broad. They may be uniformly distributed through the rock or they may be aggregated in patches, in which case they are often associated with iron ores. Mr. ALLPORT somewhat doubtfully referred them to hornblende on account of their pleochroism. The following facts, however, point decidedly to the conclusion that they must be referred to ægirine. They are sometimes idiomorphic in the prismatic zone, and when this is the case cross-sections are bounded by the traces of four prismatic and two pinacoidal faces. The angles of the prismatic faces are 87° and 93° and the pinacoids truncate the acute angles, they correspond to the form (100) which is the characteristic pinacoid of ægirine. When examined under crossed nicols the microlites extinguish parallel or nearly parallel to their length (maximum angle only 2° or 3°), and the major axis of depolarization is always the one which most nearly corresponds with the direction of elongation. In both these respects the microlites differ from hornblende and augite but agree with ægirine. ROSENBUSCH states that the *a* axis of elasticity in ægirine makes an angle of only 4° or 5° with the vertical axis. The pleochroism is not very marked, owing to the small size of the microlites, but such as it is it answers to ægirine. The colour for rays vibrating, parallel to the length of the crystal (*i.e.*, parallel to *a*) is green; that for rays vibrating at right angles to the length is often yellowish.

The rock is a typical phonolite, as Mr. ALLPORT has pointed out. It was analysed by Mr. PHILLIPS, in duplicate, with the following result:—

		I.		II.
SiO_2	...	56·46	...	56·40
Al_2O_3	...	22·29	...	22·20
Fe_2O_3	...	2·70	...	2·61
FeO	...	·97	...	·97
MnO	...	tr.	...	tr.
CaO	...	1·47	...	1·35
MgO	...	tr.	...	tr.
P_2O_5	...	tr.	...	tr.
K_2O	...	2·81	...	2·73
Na_2O	...	11·13	...	11·11
H_2O	...	2·05	...	2·05
		99·88		99·42
Sp. Gr.		2·54		—

APPENDIX TO CHAPTER X.

Melilite has already been mentioned as an accessory constituent of certain nepheline and leucite rocks. STELZNER[1] has shown that in certain basalts from the Swabian Alps, from Wartenberg on the Donau

(1) N.J. Beilage Band, II., 1882, p. 369.

and from Görlitz in Silesia, this mineral is one of the most important constituents. He proposes that these rocks should be termed melilite-basalts. Olivine and melilite are the principal constituents of these rocks. Augite also occurs, but plays a less important part than either of the other constituents. Olivine and a part of the augite occur as porphyritic constituents. The ground-mass is essentially composed of the remainder of the augite and of melilite. Nepheline, mica, magnetite and perowskite occur as important accessories. Apatite and hauyn occur sparingly. The rocks are extremely basic in composition and from 92 to 95 per cent. is soluble in hydrochloric acid with separation of gelatinous silica. BOŘICKY'S "nepheline-picrite" belongs to this group, so that BOŘICKY'S term is inappropriate.

		I.		II.
SiO_2	...	33·89	...	27·52
TiO_2	...	0·64	...	2·67
Al_2O_3	...	9·93	...	9·48
Fe_2O_3	...	15·63	...	13·37
MgO	...	16·14	...	16·64
CaO	...	15·19	...	16·75
K_2O	...	—	...	—
Na_2O	...	2·86	...	2·38
P_2O_5	...	1·41	...	1·19
CO	...	1·41	...	6·36
H_2O	...	2·90	...	3·27
		100·00		99·63

I. Melilite-basalt. Hochbohl near Owen. Swabian Alpa. STELZNER. N J. Beilage Band 1882, p. 398. Rock contains also traces of manganese, chromium and sulphur

II. Melilite-basalt. Devin. Bohemia. Analysis by BOŘICKY. Quoted from STELZNER'S paper. The rock contains also 0·27 Cr_2O_3 and ·10 S.

The distinguishing chemical characteristic of the leucite- and nepheline-bearing rocks is the high percentage of alkalies. Now there are other rocks which resemble them in this respect, but differ in containing neither of these minerals. To this group belong the keratophyres of the Fichtelgebirge and the Hartz, the rhomben-porphyry of southern Norway, the pantellarite of the island of Pantellaria, between Sicily and Tunis, and some of the augite-syenites. The most striking mineralogical feature of these rocks is the occurrence in all of them of felspars of exceptional composition, and sometimes also, as in the case of the rhomben-porphyry, of exceptional form. The name, keratophyre, was introduced by GUMBEL for certain rocks associated with the Cambrian strata (Phycoden-schiefer) of the Fichtelgebirge.(1) These rocks are according to him of variable

(1) Die palaolithiachen Eruptivgesteine des Fichtelgebirgea, p. 43.

character. Sometimes they are almost granitic in texture, at other times they are compact and hornstone-like in appearance. Sometimes they are undoubtedly intrusive rocks, at other times they appear to pass into the surrounding sediments. Their relations to the sedimentary rocks are therefore similar to those of the porphyroids and may be explained in a similar way.(1) GÜMBEL states that the rocks contain orthoclase, plagioclase, quartz, magnetite, brown mica and traces of altered hornblende.

LOSSEN has shown that similar rocks occur in the district of the Elbingerode synclinal in the Hartz, where they are associated with middle Devonian strata.(2) Five analyses of these rocks from the Hartz prove that the proportion of alkali-felspar in the rock-mass varies from 73·75 p.c. to 92·20 p.c. and that there is also considerable variability in the relative proportions of the soda- and potash-felspars; sometimes the one predominates, sometimes the other. Not only do the keratophyres vary in the amount and relative proportions of the two alkali-felspars but also in the silica-percentage. Thus, while some contain as much as 70 p.c. of silica (quartz-keratophyres) others contain as little as 50 p.c. The more basic keratophyres resemble the diabases in external appearance and occasionally become amygdaloidal.

LOSSEN describes two varieties of keratophyre which occur together in a quarry in the Braune Sumpfthal; the darker variety is fine-grained and sometimes porphyritic, the other variety is distinctly granular and of a greenish-white or dark green colour. The constituents of the rocks are felspar, biotite, augite, chlorite, iron ores and apatite. The majority of the felspars of the coarse-grained variety show a peculiar structure under crossed nicols which LOSSEN attributes to an irregular association of soda- and potash-felspar, while some of the larger felspars in the same variety may be definitely referred to micro-perthite. Similar felspars occur in the darker variety. A light yellow augite, allied to the augite of the kersantites, occurs in both varieties but is more abundant in the finer-grained rock. The chlorite is darker in colour than that of diabases and is due mainly to the alteration of the augite. The iron ores, augite and apatite are more abundant in the darker rock, and so also is the striated felspar. The two varieties are intimately associated and doubtless belong to the same eruption, but the more acid rock appears to have been the last to consolidate.

Rocks belonging to the keratophyre-group have not yet been recognized in this country,(3) but they may be looked for in the West of England. Apart from chemical analysis the peculiar character of their felspars is the most useful diagnostic feature.

The rhomben-porphyry of southern Norway when fresh is characterized

(1) See LEHMANN, Die Entstehung der altkrystallinischen Schiefergesteine, p. 83.

(2) Z.D.G.G., 1882, p. 199 and p. 455; 1883, p. 215. See also Jahr. d. preuss. geol. Landesanstalt für 1884, p. 30.

(3) In the 2nd edition of his work, Rosenbusch states (p. 418) that the rocks from Llyn Padarn, which we are in the habit of calling quartz-felsites, may be more correctly termed quartz-keratophyres.

by the occurrence of large (often three to four centimetres long) porphyritic crystals of a dark grey felspar in a violet-grey, fine-grained ground-mass. The felspars frequently give rhombic sections in consequence of their peculiar form; hence the name rhomben-porphyry given to the rock by L. VON BUCH. The ground-mass of the rock is formed of felspar, augite (slightly pleochroic in violet, brown and green tints), magnesia-mica, olivine, apatite (often in large needles) and magnetite. The altered rocks assume red tints.

A good deal of discussion has taken place as to the nature of the felspars in this rock. The porphyritic felspars are characterized by the fact that the dominant forms are T, l and y. The angle between the cleavages is approximately a right angle; at least it does not differ from this more than the cleavages in microcline. The chemical composition is difficult to determine in consequence of the occurrence of inclusions. It is certain, however, that in addition to potash there is a considerable amount of soda and lime. Under the microscope an extremely fine twinning is usually but not always recognizable. Sections parallel to P (001) extinguish parallel to the trace of M (010) when they do not show twinning and at very small angles (1° to 2°) when twinning is present; sections parallel to M do not show twinning and the extinction angle is here $5\frac{1}{2}°$–$6\frac{1}{2}°$. Sections at right angles to P and M show extremely fine twinning and sometimes possess the structure of microcline. The felspar is termed soda-microcline by BRÖGGER. It belongs to the anorthoclase group of ROSENBUSCH. The felspars of the ground-mass are referred to orthoclase by ROSENBUSCH. They are for the most part devoid of twinning. This rock is interesting to British geologists because boulders of it occur in the Eastern Counties.

The name pantellarite has been introduced by FOERSTNER[1] for certain lavas of the island of Pantellaria. The rocks are rich in iron and alkalies. They consist essentially of anorthoclase, cossyrite (a triclinic hornblende-like mineral rich in iron and soda), augite and glass.

The following analyses will give an idea of the composition of keratophyre, rhomben-porphyry and pantellarite.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2 ...	70·97	63·58	57·23	52·36	56·00	54·89	67·48
TiO_2 (ZrO_2)	0·25	—	1·29	0·29	—	—	—
Al_2O_3 ...	13·84	13·60	18·17	17·23	18·00	16·48	9·70
Fe_2O_3 ...	3·21	6·71	1·02	4·13	7·58	10·05	7·42
FeO ...	0·78	4·47	4·96	7·53			2·21
MnO ...	0·12	—	—	—	—	—	—
CaO ...	1·26	—	1·19	4·29	3·45	4·01	1·45
MgO ...	0·20	2·58	1·47	3·18	3·54	0·74	0·77
Na_2O ..	6·27	5·25	4·67	5·10	5·01	7·04	7·21

(1) Z.K. (1883). VIII.

K_2O	...	1·57	0·32	6·71	2·93	3·66	6·30	2·94
H_2O	...	0·74	2·94	3·00	3·01	0·78	0·60	0·96
P_2O_5	...	0·08	—	0·21	0·33	—	—	—
SO_3	...	tr.	—	0·08	0·16	—	—	—
CO_2	...	0·79	—	0·01	0·21	—	—	—
		100·09	99·45	100·01	101·77	98·02	100·11	100·14
Sp. Gr.	...	2·71	—	2·66	2·79	—	—	2·68

I. Quartz-keratophyre,[1] between Rübeland and Elbingerode (Hartz). JACOBS.
II. Keratophyre (GÜMBEL) from Rosenbühl, near Hof (Fichtelgebirge). LORETZ.
III. Keratophyre from the Sumpfthal (Hartz). Granular Variety. BÖTTCHER.
IV. Keratophyre from the Sumpfthal (Hartz). Fine-grained darker variety. GREMSE.
V. Rhomben-porphyry[2] from Vettakollen. KJERULF.
VI. Rhomben-porphyry from Riis. KJERULF.
VII. Pantellarite. FOERSTNER. Quoted from Roth's Beiträge, &c., 1884, p. 67.

(1) The four analyses of keratophyre are quoted from LOSSEN's paper, Jahr. d. preuss, Geol. Landesanstalt für 1884, p. 35.

(2) The analyses of rhomben-porphyry are quoted from BRÖGGER. Die silurischen Etagen, etc., p. 301.

CHAPTER XII.

Contact Metamorphism.

THE intrusion of a large mass of igneous rock is frequently accompanied by important changes in the structure and mineralogical composition of the surrounding rocks. This is especially the case when the surrounding rocks belong to the sedimentary group.

The extent of the metamorphism, other things being the same, is dependent upon the mass of the intruded rock. The character of the metamorphism is mainly dependent upon the nature of the rock affected. Much work will have to be done before we shall be in a position to give a general account of the phenomena of contact metamorphism. There are, it is true, certain general resemblances between the phenomena observed in different localities; at the same time each district exhibits certain peculiarities. The same rock, or what appears to be the same rock, is not always similarly affected. Limestone may, for example, in certain cases be merely rendered crystalline, whereas in others it may be entirely replaced by crystalline silicates such as garnet, vesuvianite, wollastonite, &c.

Having regard, then, to the local peculiarities and to the imperfect state of our knowledge it seems better to consider the facts as they have been observed in a few typical localities than to attempt a description of the phenomena in general terms. We will commence by referring to certain foreign localities in which detailed observations have been made.

The effect of the biotite-granites (granitites) of Barr-Andlau and Hochwald, in the Vosges, on a tolerably homogeneous mass of clay-slate (Steiger Schiefer) has been described in considerable detail by Professor Rosenbusch.[1] The normal rock of the Steiger Schiefer is clay-slate of a purplish colour. Blue, bluish-black, black and brown varieties may, however, be observed. The schistosity is as a rule parallel with the bedding. The rock is dull on a cross-fracture, but presents a glistening appearance on the cleavage surfaces. It contains grains and concretionary patches of quartz. Limestones and grauwackes occur in the series, but they play only a very subordinate

(1) Die Steiger Schiefer. Abh zur geol. Specialkarte von Elsass-Lothringen. Band I. Heft II. Strassburg, 1877.

part. Quartz-veins are abundant where the disturbance has been very great. Under the microscope the rock is seen to consist principally of quartz, often in more or less rounded grains, sericite in minute irregular scales, hematite in grains and hexagonal tables, carbonaceous matter and needles of a yellow or reddish yellow mineral (? rutile). The accessory minerals are pyrite, tourmaline and chlorite. As the granite masses are approached the rock changes in character. First of all dark spots make their appearance in the normal clay slate, then the matrix of the rock becomes more distinctly crystalline and the schistosity becomes less perfect. Still nearer the granite the spots become less and less marked; while in the innermost zone the rock is usually massive and spots are no longer recognizable. The term hornfels is applied to the rock of the innermost zone. Professor ROSENBUSCH divides the aureole of metamorphic rock into three zones which are not, however, separated from each other by any hard and fast lines. These three zones are designated as follows:—

(1) Zone of spotted clay-slate (knotenthonschiefer).
(2) Zone of spotted mica-slate (knotenglimmerschiefer).
(3) Zone of hornfels.[1]

The spotted clay-slate differs from the ordinary clay-slate in showing, on a fractured surface, a large number of small dark spots. These spots vary in size from that of a pin's head to that of a pea. Under the microscope the constituents of the spotted slates are seen to be essentially the same as those of the unaltered rock. Magnetite is, however, somewhat more abundant. The spots are merely portions of the slate which are somewhat richer in dark pigment (iron oxides and graphite) than the surrounding mass.

The spotted mica-slate differs from the above in being more distinctly crystalline and somewhat less fissile. The constituents show no trace of clastic origin under the microscope. The hematite of the original rock has entirely disappeared and its place has been taken by magnetite which often occurs in well-crystallized octahedra. In addition to the constituents already mentioned there occur brown mica and staurolite. The brown mica appears to take the place of the chlorite in the unaltered rock. The staurolite occurs in very small crystals (largest ·02mm). It may be recognized by its optical characters, including pleochroism, and by the fact that the prismatic angle is about 130°. The spots in the mica-slate are finer in grain than the matrix in which they lie. Their outlines are often ill-defined and finally, as the hornfels-zone is approached, they disappear altogether.

The rock of the innermost zone is usually massive in appearance and with scarcely a trace of schistosity in any direction. It is usually

(1) We use the term hornfels instead of its etymological equivalent, hornstone, because in many cases the rocks termed hornfels are distinctly crystalline and not at all like what is commonly termed hornstone in this country.

of a dark blue colour. Mica-flakes are generally recognizable. Some varieties are hornstone-like; many are, however, distinctly crystalline in appearance. The term hornfels is applied not only to the compact but also to the more or less crystalline varieties. It is used by many writers as a general name for the rock of the innermost zone in regions of contact-metamorphism, and is thus applied even to schistose and banded rocks. The schistose varieties are, however, generally designated as schistose hornfels. The dominant rock of the innermost zone in the Vosges contains andalusite, and is therefore termed andalusite-hornfels. It consists of quartz, two micas, andalusite, magnetite and hematite. Brown mica (phlogobite) is more abundant than in the preceding zone. Magnetite occurs in grains and octahedra and is more abundant than hematite. Andalusite occurs in grains and crystals with more or less rounded angles. The crystals are usually short microscopic prisms showing the forms (110) and (001). Cross sections extinguish parallel with the diagonals; longitudinal sections give straight extinction. The mineral is often colourless in thin section. The coloured sections show the usual pleochroism. In some varieties of the rock the crystals attain a considerable size and thus give rise to the porphyritic texture. In the banded (gneiss-like) hornfels layers rich in andalusite alternate with others in which this mineral is comparatively rare. The constituents of the ordinary massive (not banded) hornfels are arranged without any regularity in the rock-mass.

Prof. ROSENBUSCH describes also some local and exceptional varieties of hornfels, under the names cordierite-hornfels, garnet-hornfels and tourmaline-hornfels. The cordierite-hornfels contains irregular grains of cordierite (iolite), in which the usual inclusions of sillimanite occur. Hornblende and augite, in irregular grains, but possessing characteristic cleavages, were also observed in one locality. The smaller inclusions in the cordierite are surrounded by yellow pleochroic borders, which disappear on heating a section on platinum-foil in the flame of a Bunsen's burner, and which are accordingly supposed to be due to an organic colouring matter.

The garnet-hornfels contains garnet, pyroxene, magnetite, hematite, sphene and a colourless mica. It possesses a specific gravity of 3·024, and is evidently the result of the metamorphosis of a bed exceptionally rich in calcareous matter. The tourmaline-hornfels is schistose in structure. It is composed of tourmaline, staurolite, white mica and quartz.

The memoir of Prof. ROSENBUSCH contains an elaborate series of analyses of the different varieties of altered and unaltered rocks. These analyses show beyond all doubt that, except in the case of the tourmaline-hornfels, there has been no important alteration in the chemical composition of the rock. The metamorphosis has merely been accompanied by a more or less complete molecular rearrangement of the original constituents. The junctions with the igneous rock are sharp, and there is not the slightest evidence of a passage from the altered sediment to the eruptive granite.

The Vosges supplies us with a case in which the altered rock is very uniform in composition over considerable areas, and in which only one kind of intrusive rock (granitite) occurs on a sufficiently large scale to produce important effects. The south of Norway, on the other hand, supplies us with a case in which several varieties of eruptive rock have affected a variable group of sedimentary deposits. The metamorphic phenomena of this region have been the subject of investigation by Messrs. KJERULF[1] and BRÖGGER.[2] The following account is taken from an elaborate memoir by the latter observer. The eruptive rocks comprise sphene-bearing hornblende-granite, hornblende-syenite, granitite, mica-syenite, augite-syenite and nepheline-syenite. The sedimentary rocks, on which the principal observations have been made, belong to the Olenus and Asaphus stages of the lower Palæozoic. They comprise argillaceous and calcareous deposits of various degrees of purity. The following general laws have been established by the work of KJERULF and BRÖGGER.

(1) There is, as a rule, no alteration in the composition of the eruptive rock in the immediate neighbourhood of the junction. The change observed is merely one of texture.

(2) The different kinds of eruptive rock produce the same effects in the same kind of stratified rock.

(3) The junction between the intrusive and sedimentary rocks is always perfectly sharp. There is no sign of melting.

(4) The intensity of the metamorphism in any particular bed increases as the junction is approached.

(5) At the same distance from the eruptive rock each bed is metamorphosed in a manner depending on its composition.

The lowest rocks of the series investigated by BRÖGGER are dark bituminous and pyritous shales (alum-shales or slates), containing nodules of bituminous limestone. The dark shales become harder and lighter in colour as the junction is approached, and innumerable small spots make their appearance. The spots are rarely more than $\frac{1}{2}$ mm. in diameter. As in the Steiger Schiefer they are due to a local accumulation of pigment. In some localities the spots are not developed, the rocks in question becoming either black hornfels or chiastolite-slate. Alternations of black hornfels and chiastolite-slate may sometimes be observed. The calcareous nodules (stinkkalkellipsoide) are changed to a violet hornfels mainly composed of crystalline silicates (kalksilikathornfels). The principal minerals of these nodules are vesuvianite, felspar (mostly labradorite or anorthite), wollastonite, augite, hornblende and calcite. The plagioclase occurs in irregular colourless grains, often showing a tendency to the lath-shaped form, and having the characteristic twin structures well developed. The extinction angles indicate that the dominant felspar is of a basic species. This development of felspar in a limestone by contact metamorphism is a point of considerable interest. The wollastonite occurs

(1) Geologie Norwegens, 1880, p. 73.

(2) Die silurischen Etagen, 2 und 3, 1882, p. 324.

in grains which show characteristic cleavages and optical properties. The augite is a colourless mineral—probably malacolite. The general characters of the other minerals will be described later on. The constituents of the rock are generally without definite form. The smaller constituents are often present as extremely minute and more or less rounded (globulitic) grains.

The Ceratopyge-limestone is changed to a grey or bluish grey crystalline limestone, in which wollastonite, actinolite and vesuvianite have sometimes been developed.

The Phyllograptus-shales are converted into hornfels, chiastolite slate or spotted clay slate. Chiastolite crystals and graptolites may occur in the same rock.

The division 3 c. of BRÖGGER comprises the Megalaspis-limestone, the Expansus-beds (calcareous shales with impure limestone bands and nodules, containing *Asaphus expansus*) and the Orthoceras-limestone. Owing to its variability in lithological character and the abundance of fossils in particular beds it presents most interesting metamorphic phenomena. The Megalaspis-limestone was seen in one locality to have been converted into a grey fine-grained marble. The Expansus-beds are usually converted into thin alternating bands of flesh red (to violet) and blue (to black) hornfels. The red or violet hornfels represents the nodules and layers of impure limestone and the blue or black hornfels the intervening argillaceous layers. A flesh-red hornfels from Bagstevold was found by microscopic examination to consist of plagioclase, garnet, actinolite, colourless augite, titanite and opaque grains (iron-ores or graphite). Sometimes the calcareous nodules and bands have been converted into crystalline limestone instead of being replaced by silicates. The forms of fossils are often preserved in rocks containing wollastonite, malacolite, sphene, garnet, actinolite. Thus, in a violet hornfels from Gunildrud shells of brachiopods are replaced by coarse granular aggregates of calcite, wollastonite and magnetic pyrites; the casts of the shells being composed of compact violet hornfels.

Casts of *Orthis caligramma* in garnet occur in a garnet-hornfels from the same locality. The garnet which forms a fourth or a fifth of the entire mass of the rock is partly idiomorphic and partly in the form of the brachiopod. The Orthoceras-limestone is converted into crystalline marble in which various silicates (wollastonite, vesuvianite, garnet and actinolite) have been developed. In one case a thin stratum of the rock was entirely composed of a granular aggregate of wollastonite and garnet. Macroscopic and idiomorphic vesuvianite and garnet may be seen in some specimens.

It appears, therefore, from the researches of BRÖGGER, that the more argillaceous deposits are converted into spotted clay slates, compact hornfels and chiastolite slates, and that the calcareous rocks may either furnish a crystalline marble or a rock entirely composed of silicates. In the majority of cases the alteration is accompanied without any important change in the chemical composition of the rock, but in the case of the

development of a silicate-hornfels from a limestone the carbonic acid becomes replaced by silicic acid and probably certain bases are introduced, though detailed chemical evidence is required before the latter statement can be confidently made.

So far we have been considering cases in which the rocks subjected to metamorphism are fine-grained and more or less argillaceous or calcareous in character. We have now to consider the alteration of arenaceous rocks. The most important communication on this subject is by M. C. BARROIS.[1] The granite (granite with two micas, or granulite of French authors) of Guéméné produces important alteration on the *grès à scolithes*. The unaltered rock is a light-coloured sandstone composed essentially of quartz and white mica. The quartz occurs in rounded or irregular grains which are nearly uniform in size (·010 to ·012 mm). Scales of sericitic mica are distributed irregularly through the mass. Grains of zircon about ·08 mm in diameter are present in all the microscopic slides and there is also a certain amount of argillaceous or ferruginous matter without any definite characters. In the neighbourhood of the granite the sandstone becomes harder and darker in colour. In the first stage of metamorphism a dark mica makes its appearance and the quartz-grains lose all traces of a clastic origin. The rock becomes a micaceous quartzite. The dark mica is similar in character to that so frequently found in rocks which have suffered contact-metamorphism. It is usually without definite crystalline form. The individual scales vary in size in different specimens, the largest being found nearest the granite. They occur as a rule between the quartz-grains as if the recrystallization of the silica had in most cases preceded the development of the dark mica.

Sometimes, however, they occur as inclusions in the quartz. The liquid cavities are arranged in lines in the quartz-grains and these lines may sometimes be followed from one grain to another without a break in their continuity. The dark mica of the micaceous quartzites appears to have been developed at the expense of the sericite and of the argillaceous and ferruginous materials of the original sandstone. Nearer the granite sillimanite makes its appearance in the quartzite (quartzites micacés sillimanitisés) and is sometimes sufficiently abundant to give a silky aspect to the rock. It occurs in the form of acicular crystals which are often grouped in sheaves and bundles. The thickness of the needles is always small and never exceeds ·01 to ·02 mm. Crystalline faces are not definitely recognizable. The needles are striated parallel to their lengths and are traversed at irregular intervals by cross joints. These joints are sometimes seen to stand in direct relation to lines of liquid inclusions in the neighbouring quartz-grains. The sillimanite is colourless. It gives vivid tints under crossed nicols and extinguishes in all cases parallel to the long axis. Sometimes the sillimanite has been replaced by fine micaceous fibres. Magnetite occurs in grains and more rarely in definite crystals. It results from a change in the ferruginous matter present in the original rock.

(1) Sur les grès metamorphique du massif granitique du Guéméné. Ann. d. l. Soc. Geol. d. Nord, T. XI., p. 103.

The quartzite in the immediate neighbourhood of the granite is often traversed by veins of all sizes down to microscopic dimensions. These are sometimes discontinuous. As a result of this complicated veining the sedimentary rock is impregnated with granitic material and a felspathic quartzite is produced. The felspars belong to orthoclase, microcline and plagioclase (oligoclase). This impregnation of the quartzite with granitic material has taken place to such an extent that included fragments in the granite might be mistaken for gneiss were it not for the fact that a precisely similar rock occurs in contact with the granite and stands in visible relation with the ordinary quartzite. A similar impregnation of contact-rocks with granitic material has been described by M. LÉVY[1] and by Dr. LEHMANN.[2]

M. BARROIS recognizes, therefore, three principal varieties of metamorphic rock; (1) quartzites micacés (2) quartzites sillimanitisées and (3) quartzites felspathisés. The two former are derived from the original rock by a recrystallization of its constituents; the latter is due to a recrystallization of the original constituents accompanied by the actual addition of material from the granite.

A very interesting case of contact metamorphism has been described by Dr. HAWES.[3] An offshoot from the main mass of Albany granite intersects Mt. Willard in the form of a dyke about 300 feet wide. A distinct variety of granite, known as the Conway granite, forms the hanging wall, and an "argillitic mica-schist" the foot wall of this dyke. The Albany granite is easily recognized by its conspicuous porphyritic crystals of orthoclase, twinned on the Carlsbad plan. These crystals have somewhat rounded outlines and lie in a granitic matrix. Under the microscope the large felspars are seen to consist of interlaminations of orthoclase and albite. The ground-mass is composed of hornblende, biotite, quartz, felspar (including plagioclase), magnetite and apatite. The quartz is without form, and may often be seen filling the angular interspaces between the other constituents. Fluor and augite occur in some specimens. Square prisms of zircon are present in all. The above description applies to the normal Albany granite, and to the rock forming the central portion of the dyke. As the rock is traced towards the margin of the dyke important changes may be observed. At a distance of 100 feet from the margin the ground-mass becomes finer in texture, the porphyritic crystals remaining the same size. At a distance of 60 feet quartz begins to show traces of crystalline form. At 15 feet the quartz occurs in well-crystallized double-pyramids, and the ground-mass is no longer resolvable by the naked eye or with a lens. At the contact the matrix is almost black and flinty in aspect. Microscopic examination proves that, as the junction is approached, hornblende disappears and biotite only is present. The biotite-crystals become smaller and smaller, and the only minerals

(1) Sur les schistes micacés de Saint-Léon (Allier) B.S.G.F. 3e série. T. IX. (1881), p. 181.

(2) Die Entstehung der altkrystallinischen Schiefergesteine, Bonn 1881, p. 20.

(3) The Albany Granite, New Hampshire, and its contact phenomena. A.J.S., Vol. XXI. (1881).

unaffected by the contact are orthoclase and zircon. This fact shows that when the granitic magma reached its present position the two latter minerals were present in it as crystals.

The sedimentary rock is described as a dark "argillitic mica-schist." It occasionally contains crystals of andalusite which, however, do not appear to have anything to do with the granite. At a distance of 100 feet from the junction the only visible crystals are the rare andalusite crystals, unless the glistening aspect of the surface be regarded as indicating the presence of mica. Microscopic examination shows that this schist or micaceous clay-slate is essentially composed of quartz, white mica (sericite) and chlorite. It contains also titanic iron partially changed to leucoxene, magnetic iron and probably carbonaceous matter or graphite. Biotite and tourmaline occur only as accessories. At 50 feet from the junction no change can be observed. At 25 feet the rock is more decidedly crystalline, and biotite and tourmaline (blue within and brown without) are more abundant. From this point inward the change is very rapid. At 15 feet the rock is still schistose but hard, much fractured and full of shining dots, which indicate a new crystalline development. Biotite has increased at the expense of the original chlorite, and there is much tourmaline. Between this point and the contact the rock loses all traces of schistosity and becomes a black hornstone which breaks into small angular fragments. At 10 feet the rock gives a qualitative reaction for boron. Up to this point it has been growing coarser, now it grows finer and passes into a compact flinty hornstone, composed of quartz, biotite, tourmaline and iron oxide. Between the hornstone and the granite there occurs a band, scarcely recognizable at the top of Mt. Willard, but becoming wider as it is traced downwards, composed of a dark grey substance which is traversed in all directions by reticulated black veins. This band is composed essentially of tourmaline and quartz. The tourmaline, unlike that of the hornstone, occurs in idiomorphic crystals and often shows the most exquisite zonal banding. The rock of this band is termed tourmaline-veinstone by HAWES. It answers to the tourmaline-quartz-brochenfels of German authors. The following analyses illustrate the variation in composition in *one and the same bed*:—

	I.	II.	III.	IV.	V.	VI.
SiO_2 ...	61·57	63·35	66·30	67·88	66·41	72·26
Al_2O_3 ...	20·55	19·69	16·35	14·67	16·84	13·59
Fe_2O^3 ...	2·02	·72	·95	2·37	1·97	1·16
FeO ...	4·28	5·48	5·77	3·95	5·50	2·18
MnO ...	·10	·16	tr.	·11	·12	tr.
CaO ...	·24	tr.	·24	·30	·37	1·13
MgO ...	1·27	1·77	1·63	1·29	1·71	·06
K_2O ...	4·71	3·47	3·40	4·08	·56	5·58
Na_2O ...	·68	1·12	1·11	3·64	1·76	3·85
TiO_2 ...	1·10	1·00	1·28	·93	1·02	·45
B_2O_3 ...	—	—	tr.	·97	2·96	—
Fl ...	—	—	—	tr.	·25	—
H_2O ...	4·09	3·73	3·02	1·01	1·31	·47
	100·61	100·49	100·05	101·20	100·78	100·73
Sp, Gr. ...	2·85	2·84	2·82	2·74	2·73	2·65

I. Andalusite-bearing mica-slate; 100 ft. from junction.
II. Schist; 50 ft. from junction.
III. Schist; 15 ft. from junction.
IV. Tourmaline-hornfels; 1 foot from junction.
V. Tourmaline-veinstone.
VI. Albany granite.

These analyses show that silica, boracic acid, fluorine, and probably also soda, have been added to the schist.

Minerals of the Contact-Rocks.

Andalusite.—When this mineral occurs in more or less definite crystals it possesses a columnar habit. The crystals are elongated in the direction of the vertical axis. The crystals are, as a rule, bounded by the forms (110) and (001). The prismatic angle is 90° 50′, so that cross sections are very nearly rectangular. The a axis of elasticity is coincident with the length of the crystal and is also the acute bisectrix, so that the double refraction is negative. Longitudinal sections are lath-shaped and give straight extinction as the mineral is orthorhombic. Cross sections extinguish when the short axes of the nicols bisect the angles formed by the faces of the prism. The most perfect cleavages are parallel to the prismatic faces. These are sometimes recognizable in thin sections, sometimes not. An interesting feature of andalusite is its pleochroism. This is very often unrecognizable in thin section, and when it is recognizable it is generally distributed throughout the mineral in an irregular manner; certain portions showing the phenomena much more decidedly than others. In pleochroic crystals the phenomena are seen best in the longitudinal sections. Rays vibrating parallel to the a axis (vertical axis) are red; those vibrating parallel to the β and γ axes are colourless or pale green.

In transverse sections containing the β and γ axes no distinction of colour can, as a rule, be recognized in the ordinary thin sections. The refractive power of andalusite is higher than quartz; the double refractive power is about the same as quartz. In a large number of contact-rocks the mineral occurs without form. It then generally contains a large number of rounded grains of quartz which look like holes. These rounded grains are often so numerous as to bear about the same relation to the andalusite-substance as the holes do to the fabric in a piece of embroidery. Refraction, double-refraction and pleochroism are the only characters available for the recognition of the mineral when it occurs in this condition, and the last-mentioned character is often wanting. Andalusite often contains other minerals besides quartz as inclusions (*e.g.*, brown mica and magnetite), and it frequently happens that the arrangement of the minerals in the andalusite stands in direct relation with the arrangement of the minerals in the rock-mass. Lines of magnetite grains may, for example, be sometimes followed through a crystal of andalusite. As a general rule however, the crystallization of the andalusite appears to have

affected the distribution of the other constituents. Mica, for example, is less abundant in the andalusite than it is in the other portions of the rock. The spots in certain spotted-schists are, as Mr. WARD pointed out, merely undeveloped (that is, undeveloped so far as form is concerned) crystals of andalusite. Such spots must not be confused with those which are due to a local heaping up of pigment. They belong to a totally different category and occupy a different position in the zone of metamorphic action. Andalusite is a silicate of alumina (Al_2O_3, SiO_2). It occurs in argillaceous sediments near granitic masses and also in crystalline schists. The andalusite-schists of Aberdeenshire, described by Mr. HORNE[1], are similar to many contact-rocks. Unless we assume the existence of an underlying mass of granite, which is nowhere exposed, or the former existence of an overlying mass, we must agree with Mr. HORNE that these rocks are the result of regional metamorphism.

Chiastolite.—This mineral is closely related to andalusite. It possesses the same composition and the same prismatic angle. It is developed in long prisms. Cross-sections of these prisms are nearly rectangular. Oblique sections are more or less lozenge shaped. The peculiarity of chiastolite lies in the fact that the central portion of the crystal is usually occupied by inclusions of dark substance corresponding to the matrix of the slate or schist in which the chiastolite has been developed. The outlines of the central patch in any section correspond with those of the crystal itself. Lines of dark inclusions run out from the angles of the central patch to those of the crystal itself (*macle tétragramme* of HAÜY). Sometimes the angles of the prisms are occupied by four dark rhombs corresponding in form with those of the central core (*macle pentarhombique* of HAÜY). Chiastolite occurs in clay-slates near granite-masses. Sometimes chiastolite and andalusite occur in the same rock. As a rule, however, the chiastolite is found in the outer zone of metamorphic action, whereas andalusite is more characteristic of the inner zone and is often found in the rock which is in actual contact with the granite, as in the Lake District, Wicklow and Cornwall.

Staurolite.—This mineral is also orthorhombic. The common forms are (110), (001), (010) and (101). Longitudinal sections are rectangular; cross sections often nearly hexagonal. The prismatic angle is about 130°. The mineral often occurs in the form of penetration twins. When the two individuals form a rectangular cross the twin plane is a brachydome (032); when they cut each other at an angle of about 60° the twin plane is (232). Refraction and double-refraction are both strong. The vertical axis is the acute bisectrix and the double-refraction is positive. The pleochroism is given by ROSENBUSCH as follows: a and β yellowish red often with a trace of green; γ hyacinth-red to blood-red. Staurolite is more complex in composition than the other aluminous silicates which are

(1) M.M., Vol. VI. (1884), p. 98.

developed in contact-rocks. In addition to alumina it contains iron and magnesia. It occurs as a contact mineral and also as a constituent of certain crystalline schists. The small crystals in the spotted mica-slate of the Vosges rarely measure more than ·02mm. in length. They are distinguished from andalusite by the form of the cross section and by the fact that the vertical axis is coincident with the γ axis of elasticity.

Sillimanite (Fibrolite).—This mineral occurs in long and for the most part extremely thin prisms. The prisms are separated at intervals by cross joints. When they are not too thin they appear colourless. Very thin prisms may appear opaque in consequence of total reflexion at their margins. As a rule the forms cannot be determined in thin sections. The prismatic angle is about 97° and the prism faces are often striated parallel to the long axis. Refraction and double refraction are both higher than quartz. The γ axis is coincident with the length of the crystal. Sillimanite occurs in certain sandstones metamorphosed by contact with granite-masses. Professor ROSENBUSCH also observed it in association with cordierite in the cordierite-hornfels of the Vosges. It is also a constituent of certain crystalline schists (*e.g.*, fibrolite-gneiss). It is identical in composition with chiastolite and andalusite.

Dipyre.—This is a mineral of the scapolite group. It has not been recognized in this country but occurs, both in limestones and slates, near granite-masses in the Pyrenees. It is colourless in thin section. The refractive index of the mineral is about the same as that of quartz, the double-refractive power is greater than that of quartz. External crystalline form is wanting in the rock-forming members of the scapolite group, except where they occur in limestones. All members of the group are uniaxial and negative.

Cordierite is rare as a contact mineral. It is found in the Vosges and Mr. DILLER[1] records it as occurring under similar conditions in the Troad. It is without form in the contact-rocks. The most useful diagnostic characters are refraction, double-refraction and the nature of the inclusions. The latter consist of fibrolite- or sillimanite-needles and minute bodies round which there is a yellow pleochroic border.

Garnet is very commonly present in contact-rocks and is sometimes so abundant as to make up the bulk of the mass. It occurs in well-crystallized dodecahedra, irregular grains and compact masses (allochroite). The variety known as grossularia is especially characteristic of limestones when altered by contact with igneous rocks. The red varieties (almandine) are more common in impure argillaceous rocks. Allochroite is found in the St. Just district, on the west side of the Land's End mass of granite.

Mica.—Both white and brown or black micas occur in the contact-rocks. In the absence of tourmaline the micas generally

(1) Q.J.G.S., Vol. XXXIX. (1883), p. 627

increase in size as the junction is approached. They are, as a rule, devoid of external crystalline form. The dark mica is highly characteristic of contact-rocks. It often occurs in minute irregular overlapping scales. Its colour is usually less marked than that of the black mica in igneous rocks and it rarely if ever shows definite boundaries in the prismatic zone. When inclusions of zircon occur they are generally surrounded by pleochroic borders as in the igneous rocks. The brown mica takes the place of chlorite and to some extent also that of the sericite of the original rock. It may, by subsequent alteration, again give rise to chlorite, as in some of the Cornish contact-rocks. White mica and brown mica frequently occur intergrown with each other. The secondary mica in some of the Cornish rocks is often of a reddish brown colour.

Wollastonite.—This mineral is especially characteristic of calcareous rocks. It is monoclinic but elongated in the direction of the ortho-diagonal axis, so that longitudinal sections give straight extinction. In this respect it resembles epidote. Cross sections of good crystals are six- or eight-sided and are bounded by the traces of the forms (001), (100), ($10\bar{2}$) and (101). The most perfect cleavages are parallel to 001 and 100. The angle between these two faces is 95° 30′. The optic axial plane is the clino-pinacoid and it is therefore at right angles to the direction of elongation as in epidote. The extinction referred to the trace of 001 in a clino-pinacoidal (cross) section is 32°. Refraction and double-refraction are both high, but not so high as in the normal monoclinic pyroxenes. In thin sections the mineral is colourless.

Pyroxene.—Normal pyroxene is often developed in rocks containing more or less calcareous matter. It is frequently found in limestones and in lime-silicate-hornfels in association with wollastonite. It is usually colourless in thin section and occurs in the form of more or less rounded grains in which, however, the characteristic cleavages and optical properties may be recognized.

Hornblende-group.—Actinolite and tremolite occur in certain rocks near granite masses. The occurrence of calcareous matter in the original rock is necessary for their formation, so that they are not developed in purely argillaceous sediments.

Felspar.—The occurrence of felspar as a contact mineral was first demonstrated by Mr. ALLPORT[1] in the case of a rock occurring at Enniscorthy, Co. Wexford. Professor BRÖGGER has since recorded the occurrence of felspar (mostly plagioclase) in several contact rocks from Southern Norway. In the metamorphosed limestone-nodules (stinkkalkellipsoide) of the alum-slates it occurs in "long, lath-shaped, irregularly-bounded individuals showing twin striation." The extinc-

(1) Q.J.G.S., Vol. XXXII. (1876). p. 411. Professor ROSENBUSCH throws doubt on this identification of felspar in a contact-rock by Mr. ALLPORT, Mik. Phys. Band II. (1886), p. 53. The present writer has examined Mr. ALLPORT's specimens, and has no doubt as to the existence of felspar in this rock.

tion angles are high and indicative of labradorite or anorthite. M. BARROIS has recorded the occurrence of felspar in a sandstone of Brittany. In this case the felspar is due to an impregnation of the sedimentary rock with granitic material. It is found only in the immediate neighbourhood of the granite.

Iron ores.—The amorphous iron oxides and hematite of the unaltered sediments are converted into magnetite by igneous intrusions. The magnetite may occur in grains or octahedra.

Quartz.—This mineral undergoes recrystallization in the process of contact metamorphism. In the arenaceous rocks and the clay-slates the original boundaries of the quartz grains disappear, so that the mineral loses all traces of its clastic origin. The brown mica, so characteristic of contact metamorphism, sometimes occurs as inclusions in the recrystallized quartz.

Tourmaline.—This mineral is very characteristic of contact metamorphism in certain districts. It may occur as idiomorphic crystals, as large irregular crystalline masses moulded on the other constituents, or as small grains. It may be brown, blue, green or nearly colourless. The larger crystals sometimes show a very perfect zonal structure. Minute inclusions in the tourmaline are often surrounded by borders of a colour different from that of the main mass. Thus in brown tourmalines the borders in question are often green.

DESCRIPTION OF THE ROCKS.

West of England.—The granite-masses of Devon and Cornwall have, in certain places, produced important effects on the sedimentary rocks of the district. These effects are by no means uniform in their character. Sometimes they may be traced to considerable distances from the granite, at other times they are very local and unimportant. It is an unfortunate circumstance that the distribution of the different varieties of contact-rocks is not delineated on the Survey Maps. Each granite-area is surrounded by a wash of colour of uniform width, which is supposed to represent the zone affected by the granite. As a matter of fact the metamorphic zone is not of uniform width, and therefore the colour which is supposed to indicate it is somewhat misleading. That the rocks in the immediate neighbourhood of the granite are, in many cases, different from the normal rocks of the district was noticed by the earlier writers on the geology of the West of England. Thus Dr. BOASE [1] proposed the terms *cornubianite* and *proteolite* for certain varieties of rock occurring near the junctions of the sedimentary rocks and the granite. The definitions which he gives of these terms do not, however, enable us to use them with any degree of precision at the present day. The term cornubianite has been used to a certain extent by continental writers, but not in any very consistent sense. The term proteolite has never made any way in petrographical literature. Dr. BONNEY has proposed [2] that the term

(1) On the Geology of Cornwall. Trans. Roy. Geol. Soc. Corn., Vol. IV., p. 394.

(2) Q.J.G.S., Vol. XLII. (1886), Proc., p. 104.

cornubianite should be applied to the tourmaline-bearing contact-rocks, and that the term proteolite should be revived for those consisting essentially of quartz, mica and andalusite. If this suggestion were adopted cornubianite would then be equivalent, or approximately equivalent, to the tourmaline-hornfels of continental petrographers and proteolite would be equivalent to andalusite-hornfels. Confusion would probably be saved if petrographers would consent to drop both terms and content themselves with describing the rocks they meet with in general terms.

De la Beche calls attention to the influence of granite on the surrounding rocks,[1] and emphasizes the fact that each variety of rock has its own special type of metamorphism. Thus he says: "Where the grits of the carbonaceous series closely approach the granite on the north-west of Dartmoor, as at White Hill, near Lidford, we find them taking the character of quartz rock, and other instances of the same kind may be observed from thence round by Okehampton. Wherever slates come into contact with this granite, they become changed in appearance, some having been rendered flinty . . . . In numerous localities we find the coarser slates converted into rocks, resembling mica-slate and gneiss, a fact particularly well exhibited in the neighbourhood of Meavy, on the south-east of Tavistock . . . . It would be uselessly occupying time to attempt a description of all the altered rocks which occur in Cornwall, inasmuch as the varieties are as considerable as the composition of the rocks brought under the necessary conditions. The slates not unfrequently become extremely hard and of a dark colour—dark purple is by no means an uncommon tint. Another common variety consists of a glossy grey slate often containing disseminated and imperfect crystals of a mineral resembling chiastolite."

Mr. Allport has described the microscopic structure of some of the contact-rocks surrounding the Land's End mass of granite.[2] The rocks which he describes may be divided into two groups: (1) those which contain tourmaline and (2) those which do not, or those which contain it only in very small quantity. Examples of both types may be obtained at Mousehole, near Penzance. The rocks in question are essentially composed of quartz, brown or reddish brown mica, white mica and tourmaline. They usually exhibit a foliated texture, and are described by Mr. Allport as tourmaline-schists and mica-schists. The rocks are holo-crystalline and the individual constituents exhibit no trace of a clastic origin. There has been a complete recrystallization of the original constituents accompanied, at any rate in the case of the tourmaline-bearing rocks, by the actual addition of material (*e.g.*, boracic acid). The phenomena are in many respects similar to those described by Dr. Hawes in his paper on the New Albany granite. On the west side of the Land's End mass of granite the contact-metamorphism

(1) Report on Geology of Devon and Cornwall, p. 267.

(2) Q.J.G.S., Vol. XXXII. (1876), p. 407.

is very marked about Cape Cornwall and Botallack. Here Mr. ALLPORT observed both tremolite and andalusite [1] as accessory constituents in the contact-rocks. The mode of occurrence of the tremolite in a rock from Botallack is exceptionally interesting. It occurs in long bladed crystals which often cross the planes of foliation without in any way affecting them. Lines of black granules pass uninterruptedly through the tremolite blades. Here we have undoubted evidence of the development of idiomorphic crystals in a rock which has certainly never been fused. The andalusite was observed by Mr. ALLPORT in a rock from Cape Cornwall.

The granite of Trewavas Head has produced important alterations, similar in many respects to those described by Mr. ALLPORT. The phenomena may be well studied at both the western and eastern junctions. On the eastern side the "killas" has been traversed by broad bands of granite, which are in no way affected by the powerful mechanical forces that have crumpled and cleaved the former rock. The altered "killas" preserves its fissile structure right up to the actual junction, except where it has been converted into a rock composed of tourmaline and quartz. The fissile rock is a highly micaceous slate which often presents a spotted appearance (knoten-glimmer-schiefer). The constituents are quartz, white mica, chlorite, andalusite, tourmaline and magnetite. The white mica sometimes occurs in very large plates, which are mostly arranged with their flat surfaces parallel to the planes of schistosity. The chlorite appears to take the place of the brown mica so characteristic of contact metamorphism. It contains minute inclusions surrounded by pleochroic borders, and is probably a secondary product resulting from the alteration of the brown mica. Brown tourmaline is present only in very small quantity. It occurs as minute crystals. The andalusite is not recognizable in all slides. It is without definite crystalline form. The tourmaline-rock is of a dark brown colour. It is composed essentially of brown tourmaline, in grains or crystals, and quartz. Some varieties contain a considerable amount of brown mica of the same colour as the tourmaline. The two minerals may, however, be readily distinguished by the fact that the more or less lath-shaped sections appear dark in opposite positions when the stage is rotated over the polarizer. The relation of the tourmaline-rock to the ordinary micaceous-slate is very interesting in certain places. It (the tourmaline rock) is found on either side of joint-planes which traverse the altered killas at right angles or approximately at right angles to the schistosity. This relation is readily explained if we regard these joint planes as having been the channels by which vapours, including boracic acid, obtained access to the rock; indeed it can be explained on no other hypothesis. The veins which produce the metamorphism above described are composed of a tourmaline-bearing muscovite granite, in which topaz

(1) Mr. ALLPORT speaks doubtfully about the occurrence of andalusite. His slides, however, show that in this instance he has been unnecessarily cautious. The mineral possesses the characteristic pleochroism, refraction and double-refraction.

may sometimes be recognized as an accessory constituent. The main mass of the granite contains black as well as white mica.

Mr. WORTH[1] has described the contact metamorphism produced by the Dartmoor granite. He says: "The alteration in the adjacent belt of slates, as a rule, proceeds so systematically that it would be quite possible with a little trouble to locate, within a very few yards, the position of a stray specimen from any given area. There are, however, differences in the changes in different localities, apparently due to two causes—first, the original character of the rock altered; secondly, the relation borne to it by the granite in bulk and position." The common type of metamorphism along the southern border of the granite area is the conversion of the ordinary clay-slates into spotted-slates "by the development of nodules or crystals, more or less imperfect, of andalusite or its variety chiastolite." As the granite is approached the rocks become more and more micaceous and finally pass into micaceous schists or into a massive rock which has lost all distinctive traces of its original fissile structure (hornfels). Chiastolite slate occurs at Ivybridge; andalusite slate at Cornwood.

Leicestershire.—An interesting case of contact metamorphism may be observed in Brazil Wood near Mount Sorrel. It has been described by Mr. ALLPORT.[2] The granite which has produced the metamorphism is hornblendic and, near the junction, appears somewhat porphyritic in consequence of the development of well-formed oligoclase-crystals. Under the microscope these crystals show a well-marked zonal banding and the usual polysynthetic twinning. The ground-mass is composed of quartz, turbid felspar, dark mica, magnetite and a little hornblende. Garnet occurs as an accessory constituent. The junction with the altered rock is sometimes sharp and sometimes ill-defined, as if the constituents of the granite had impregnated the surrounding rock for a short distance. The altered rock is exposed only in one small quarry so that no information can be obtained as to the progressive changes as the granite is approached. The common variety of altered rock is a highly micaceous hornfels. This variety is, however, sometimes banded with a compact rock in which mica is rare. It is evident that the original sediments varied in character, and that the different beds have been differently affected. The micaceous rock is essentially composed of two micas, quartz and magnetite. In some specimens the dark mica has been changed to chlorite. The individual constituents are arranged without order in the rock. The compact rock is mainly composed of an aggregate of water-clear grains having the refraction and double-refraction of quartz or felspar. It also contains magnetite, a few flakes of mica and a considerable number of minute rounded grains of colourless garnet. Red garnets occur in well-formed dodecahedral crystals in certain varieties of the rock. They are almost always associated with quartz grains which sometimes form a kind of irregular

(1) Trans. Plymouth Inst., &c., 1886. Vol. I., pp. 19-44.

(2) G.M. Decade II. Vol. VI. (1879), p. 481.

zone round the garnets. The following is an analysis of the micaceous rock by Mr HOUGHTON.[1]

SiO_2	...	54·01
Al_2O_3	..	21·87
Fe_2O_3	..	5·38
FeO	...	6·24
MnO	...	0·63
CaO	..	2·13
MgO	...	1·30
K_2O	...	3·56
Na_2O	...	1·00
H_2O	...	4·23
		100·45
Sp Gr.	...	2·85

Lake District.—The alteration of the Skiddaw slate by the Skiddaw granite which is exposed at the surface in Sinen Gill and the Caldew Valley is thus described by Mr. WARD:[2] "On approaching the altered area, the slate first becomes faintly spotty, the spots being of a somewhat oblong or oval form, and a few crystals of chiastolite appear. Then these crystals become more numerous, so as to entitle the rock to the name of Chiastolite Slate. This passes into a harder, more thickly bedded, foliated and massive rock, Spotted (or Andalusite) Schist; and this again into Mica Schist of a generally grey or brown colour, and occurring immediately around the granite." In the chiastolite slate the crystals of chiastolite are often very long in proportion to their width. They lie irregularly in the slate without reference to the cleavage planes. Fossils have been found in slates containing well-developed chiastolite. (See Fig. 2, Plate XXXIII.)

The spotted schist forms an inner zone. It is more distinctly crystalline than the chiastolite slate. The spots are more or less rectangular or ellipsoidal in form, the longest diameters lying in the plane of foliation. When examined in thin section and by transmitted light the spots are seen to be lighter in colour than the rest of the slide. This is due to the fact that the scales of brown mica which enter largely into the composition of the rock are crowded together between the spots. Minute opaque rods and grains are, however, as abundant in the spots as in other portions of the slide. Under crossed nicols the spots show a definite extinction and are thus seen to be largely composed of some crystalline substance Mr. WARD regarded them as undeveloped (that is undeveloped so far as form is concerned) crystals of chiastolite. One point is clear; they are different from the spots described by Professor ROSENBUSCH, for they are certainly not due to a local heaping up of the pigment in certain places.

The rock from the immediate neighbourhood of the junction is still more coarsely crystalline and mica is very conspicuous. Under the

(1) Q.J.G.S., Vol. XXXIV., 1878, p. 224.

(2) Geology of the Northern Part of the Lake District. Survey Memoir, p. 9.

microscope this rock is seen to be composed of deeply-coloured reddish brown mica, white mica, quartz, opaque rods and grains, andalusite and a few grains of colourless garnet. The reddish brown mica is strongly pleochroic and the minute inclusions are surrounded by deeply-coloured borders. It is sometimes intergrown with the white mica and both varieties occur as plates of considerable size. Andalusite occurs as small prisms and large irregular masses. It occasionally shows the characteristic pleochroism. The garnet is present only as an accessory constituent

The Shap granite produces important alteration in the surrounding rocks, but the nature of this alteration has not as yet been studied in detail. Messrs. HARKNESS and NICHOLSON[1] call attention to the occurrence of vesuvianite (idocrase) in a white crystalline limestone (Coniston limestone) at Wastdale Head Farm. This mineral, as we have already seen, is eminently characteristic of the contact metamorphism of limestone.

Scotland.—The granite masses of Kirkcudbright have produced great changes in the sedimentary rocks with which they are associated, and some information as to the character of these changes will be found in the Survey memoirs. No descriptions of the microscopic characters of the rocks have as yet been published. In Skye, near Broadford, Ordovician limestone has been converted into white saccharine marble by contact metamorphism, and vesuvianite is recorded from the same locality. The marbles of Assynt, described by Dr. HEDDLE,[2] may be examples of contact metamorphism for they occur in the immediate neighbourhood of an extensive mass of igneous rock, and contain minerals (malacolite, wollastonite, &c.) such as are known to be developed in limestone by the action of igneous rocks.

Ireland.—The contact metamorphism produced by the Wicklow granite has been described by Professor VON LASAULX.[3] The lower Palæozoic sediments become more and more crystalline as the granite is approached. In the neighbourhood of Killiney the rock near the granite is a micaceous schist. The principal constituents are quartz, two micas and andalusite. The andalusite is especially abundant in certain layers. Small prisms of brown tourmaline also occur. There appears to be no development of typical hornfels. Mr. ALLPORT'S observation of the occurrence of felspar in a contact-rock from Enniscorthy, Co. Wexford, has been already referred to.

The granites of northern Galway appear to have produced important alteration in certain limestones. Thus at Bunbeg the limestone near the granite is highly crystalline and contains numerous garnets.[4] Vesuvianite is also recorded from the altered limestones of Donegal.

In this chapter we have referred more especially to the alteration effected by granites and allied rocks. The contact metamorphism produced by diabase or dolerite has already been described (see page 217).

(1) Q.J.G.S., Vol. XXXIII., 1877, p. 466.
(2) M.M., 1884, p. 271.
(3) T.M.M. Neue Folge, Band I., p. 135.
(4) Dr. CALLAWAY. Q.J.G.S., Vol. XLI., p. 227.

CHAPTER XIII.

Origin of Igneous Rocks.

IGNEOUS rocks, as we have already stated, are those rocks which have resulted from the consolidation of molten magmas. The evidence of this mode of origin, so far as regards the volcanic rocks, is complete and satisfactory. Molten masses are seen to issue from volcanoes and to consolidate as more or less crystalline rocks; moreover, it is possible, as we shall presently show when we describe the remarkable synthetic experiments of Messrs. Fouqué and Lévy to reproduce such rocks as basalt, andesite and tephrite by pure igneous fusion. When, however, we pass from the consideration of the volcanic to that of the plutonic rocks the evidence is not so satisfactory. Granite, diorite and gabbro have never been seen to form at the surface of the earth, and all attempts to reproduce them artificially have failed. Nevertheless, when we study the geological, chemical and mineralogical relations of the plutonic to the volcanic masses, and note the transitional forms, we are driven to conclude that the former have resulted from the crystallization of a mass of material similar to that which has yielded the latter, and that the difference between the two types of rock is a consequence of the fact that the consolidation has taken place under different conditions as to temperature and pressure.

The origin of plutonic masses is still further complicated by the fact that they show a double kind of relationship. On the one hand they are closely connected with volcanic rocks, and on the other with the rocks which constitute the banded crystalline group. Those geologists who have regarded the banded gneisses as metamorphosed sedimentary rocks have looked upon the massive rocks, associated with them, as representing the extreme phase of metamorphism, and have spoken of these massive rocks as metamorphic granite, metapmorhic gabbro, &c., &c. That sedimentary rocks have occasionally been melted down may be regarded as highly probable, though there does not appear to be any direct evidence of this having taken place on a large scale; but that the crystalline schists, banded gneisses and igneous rocks, taken as a whole, have resulted from the metamorphosis

and fusion of normal sedimentaries (sandstones, clays, limestones, dolomites, salt-beds, &c.), appears to the present writer highly improbable. The effect of denudation and deposition is to separate the chemical constituents of igneous rocks and banded gneisses into portions which are soluble and others which are insoluble under ordinary surface conditions. The alkalies, lime, magnesia and iron largely pass into solution. The most important insoluble constituents formed in connection with the breaking up of the crystalline rocks are kaolin and quartz. Of the soluble constituents iron is readily precipitated as ferric oxide wherever oxygen obtains access to the solutions. It may also be separated as carbonate under those peculiar and little-known conditions which result in the conversion of beds of limestone into ironstone. Magnesia may assume the solid form again by the obscure process generally known as "dolomitization." Organic life restores to the solid crust of the earth the lime which is removed in solution. The alkalies are, however, restored to the land under very local and exceptional conditions, and it is doubtful whether the total alkalies present in beds of rock-salt, carnallite, &c., are comparable in amount with the alkalies which have been removed in solution during geological time. To produce, therefore, an igneous rock by the melting of sedimentary rocks, it would in general be necessary to collect together samples of the necessary ingredients from different portions of the earth's crust. The local melting of sedimentary rocks could only produce normal igneous products under exceptional circumstances.

Another argument against any speculation which would connect the igneous and banded crystalline rocks on the one hand, with the normal sedimentary rocks on the other, in any kind of cycle, may be drawn from the fact that the latter appear to be insignificant in bulk when compared with the former. If the sedimentary rocks were totally removed from the planet its importance as a member of the solar system would not be appreciably affected.

Admitting, then, that we are profoundly ignorant as to the precise conditions under which molten masses originate, let us consider certain facts which throw some light on the phenomena accompanying consolidation.

Any homogeneous liquid mixture containing two or more definite chemical compounds may be termed a solution, no matter at what temperature the mixture may commence to solidify. It is customary in the case of solutions to regard one of the constituents as the solvent medium. Thus, in the case of a solution containing salt and water, at ordinary temperatures the salt is said to be dissolved in the water. This distinction between "the dissolver" and "the dissolved," though very apparent in such a case as that which has just been mentioned, where the phenomena of solution are studied at temperatures considerably below the fusing point of one of the constituents and above the fusing point of the other, become less marked when studied at temperatures

nearer the fusing point of either of the constituents. Thus TILDEN and SHENSTONE[1] have shown that, taking different salts soluble in water, the rate of increase of solubility with temperature above 100° C. stands related to the melting point—the lower the melting point of the salt the more rapidly will its solubility increase with temperature. They also show that benzoic acid which melts at 120° C. is miscible with water in any proportion at a few degrees above this temperature. Such a mixture may still be regarded as a solution, but it is no more correct to say that the benzoic acid is dissolved in the water than it is to say that the water is dissolved in the benzoic acid. Dr. GUTHRIE[2] in one of his most important papers on cryohydrates and eutectic mixtures also calls attention to the fact that water and certain fused salts are miscible in all proportions, and that an extremely small quantity of water has the effect of lowering the fusing point of the salt. Thus 1·14 p.c. of water lowered the fusing point of nitre from 320° C. to 300° C., *i.e.*, no less than 20° C.

The distinction between "dissolver" and "dissolved" also becomes somewhat confused if we consider the phenomena accompanying the solidification of solutions. Take the case of nitre and water. Dr. GUTHRIE has shown that a solution containing 11·2 p.c. of nitre will solidify as a whole at a temperature of −3° C. and he gives the name cryohydrate[3] to the mixture containing this percentage of nitre. On cooling a solution containing more than 11·2 p.c. of nitre the salt crystallizes out until the temperature of −3° C. is reached, when the mother liquor will be found to contain 11°·2 p.c. of nitre and to solidify at −3° C. On cooling a solution containing less than 11·2 p.c. ice crystallizes out, and when the temperature of −3° C. is reached the mother liquor will be found to contain the same percentage of salt as before. In short, take any aqueous solution of nitre and cool it to − 3° C.: the mother liquor at that temperature will have a constant composition and will solidify at that temperature provided heat can escape. We see, therefore, that between the solidifying point of ice and the solidifying point of the cryohydrate the order of crystallization of the two constituents does not depend upon their fusibilities but on the relative proportions of the two constituents. Which constituent is to be regarded as the solvent medium between 0 C. and −3° C.? Shall we say that the nitre is dissolved in the water? or the ice in the nitre?—or would it be preferable to regard both salt and nitre, when either are present in excess of the proportion existing in the cryohydrate, as dissolved in the cryohydrate? The best plan appears to be to look upon solution as a liquid mixture of two or more compounds without attempting to determine in every case which compound should be regarded as the solvent medium.

A solution is said to be saturated with any particular compound when

(1) Phil. Trans., Vol. CLXXV. (1884), p. 36.

(2) Phil. Mag., Vol. XVIII., 5th Se. (1884), p. 114.

(3) Each salt soluble in water is capable of forming with water a cryohydrate. Thus the cryohydrate of common salt contains 23·6 p.c. of salt and solidifies at −5° C. See papers by DR. GUTHRIE: Phil. Mag., 4th Series, Vol. XLIX.; 5th Series, Vols. I., VI., XVII. and XVIII.

a change in temperature (generally a lowering) causes the separation of that compound. It is said to be super-saturated when it is cooled below the temperature at which the compound would separate if crystals of that compound were present. When once crystals start to grow in a super-saturated solution they do so rapidly and the temperature rises. A liquid may be over-cooled, and in this condition crystallization, when once started, proceeds rapidly and the temperature rises to the normal consolidating point.

Dr. SORBY has shown that pressure decreases the solubility of those salts which expand on dissolving. Hence, in solutions of such salts, increase of pressure will act in the same way as decrease of temperature. Moreover, it follows, as a consequence of the same principle, that a substance may crystallize from a solution under great pressure at a higher temperature than it would crystallize from the same solution under a low pressure; and, further, that relief of pressure may be followed by a solution or corrosion of pre-existing crystals.

A homogeneous solution remains homogeneous so long as the temperature remains uniform, but a disturbance in the equilibrium of temperature brings about heterogeneity in the solution. The compound or compounds with which the solution is nearly saturated tend to accumulate in the colder parts. This important principle has been established by SORET[1] and may therefore be referred to as SORET'S principle. Vertical tubes containing aqueous solutions of various salts in various proportions were placed under such conditions that their upper portions were maintained at a temperature of 80° and their lower portions at 20°. The experiments were continued for about fifty days. In every case the same feature was observed—there was always a motion of the salt towards the colder parts; or, in other words, the passage of heat through the solution was accompanied by a passage of salt in the same direction.

Reference has already been made to Dr. GUTHRIE'S researches on cryohydrates. It follows from these researches that each salt which is soluble in water is capable of forming with water a mixture (or compound) which possesses a constant solidifying point and a constant composition. An important question arises as to the nature of these cryohydrates. Are they definite chemical compounds or are they simply mixtures of definite compounds which have a fixed melting point? Some light may be thrown on this point by a microscopic examination of the corresponding mixtures of certain anhydrous salts.

Nitre fuses at 320°; nitrate of lead is infusible without decomposition. Nitrate of lead is soluble in liquid nitre, just as salt is soluble in water. If we mix nitrate of lead and nitre in the proportion of 46·86 of the former to 53·14 of the latter, the solution may be cooled to 207° C. without the separation of either of the constituents.[2] At this temperature the whole mass will consolidate, provided the

(1) Ann. Chim Phy. Paris, 1881 (5) 22, p. 293.

(2) GUTHRIE. Phil. Mag., 5th Series. Vol. XVII., p. 470.

heat developed by consolidation be allowed to escape. Call this the first experiment. If the proportion of nitrate of lead be greater than that given above then, before the temperature of 207° C. is reached, sufficient nitrate of lead will separate out to produce a solution in which the two constituents are present in the same proportion as in the first experiment. As more heat is withdrawn the mother liquor will consolidate at the fixed temperature of 207° C. If nitrate of lead be present in the original solution in smaller quantity than in the first experiment, then, on cooling down to 207°, nitre will separate in such quantity as to produce a mother liquor containing 46·86 p.c. of nitrate of lead. It follows, therefore, that if we take any liquid mixture of nitre and nitrate of lead and cool it to 207°, the portion remaining liquid at that temperature will have a constant composition and a constant solidifying point; moreover, the solidifying point of the mixture will be lower than that of either of the constituents taken separately. Dr. GUTHRIE'S researches prove, therefore, that fused mixtures are strictly analogous to aqueous solutions. Seeing that any two substances which are capable of forming together a homogeneous liquid will, when mixed in a certain proportion, consolidate simultaneously at a fixed temperature which is lower than that at which either of the two substances can be melted when taken separately, Dr. GUTHRIE proposed that a mixture (or compound) of the two substances in the required proportion should be termed an eutectic mixture (or compound) from εὖ τήκειν, to melt easily. Now, if a drop of the solution of nitrate of lead in nitre, in eutectic proportions, be placed on a hot glass slide under the microscope then, as the solution cools, strongly double-refracting crystalloids (VOGELSANG) are first seen to form in great numbers, and immediately afterwards the portion remaining liquid consolidates as a confusedly crystalline mass or as a fibrous aggregate often showing the most beautiful radial structures. It is impossible to be certain as to the precise nature of the crystalline bodies,[1] but the phenomena observed do not bear out the view that the mass which consolidates at 207° C. is one definite chemical compound. Somewhat more positive conclusions can be drawn from a study of a solution of potassium chromate in nitre. The eutectic mixture of these substances contains 3·76 p.c. of the former salt and consolidates at 295° C. If fused nitre be allowed to crystallize on a microscopic slide under a cover-glass it forms an aggregate of crystalline grains or rather plates. The plates mutually interfere with each other, but each possesses definite optic characters. Those which lie nearly at right angles to an optic axis are seen, in convergent polarized light, to be uniaxial and negative.[2] Now when

(1) The writer of this work is responsible for the descriptions of the microscopic characters of the eutectic compounds.

(2) Nitre is dimorphous. When formed at low temperatures from aqueous solutions it is orthorhombic. When formed at high temperatures from fusion or anhydrous solutions it is rhombohedral.

the eutectic mixture is allowed to consolidate the structure varies somewhat according to the conditions of cooling. The substratum, so to speak, is an aggregate of crystalline plates similar in optical characters to those obtained by cooling fused nitre, *i.e.*, they are uniaxial and negative. This shows that nitre crystallizes as nitre in the eutectic compound at a temperature 113° C. below its normal fusing point. The chromate of potassium is sometimes distinctly recognizable in the form of minute, yellow microlites enclosed in the nitre; more frequently, however, it cannot be recognized as occurring in distinct microlites. In the latter case it is distributed through the nitre in yellowish anastomosing veins or in minute striæ which are often only distinctly visible under a very high power. The distribution of the minute striæ appears to be determined, at any rate in places, by the internal structure of the nitre; *i.e.*, the striæ lie along crystallographic planes. A study of the microscopic structure of the eutectic mixture of nitre and potassium chromate leads, therefore, to the conclusion that, notwithstanding the fact that it has a constant composition and a constant solidifying point, it is in reality a mixture and not a chemical compound—nitre crystallizes as nitre and chromate of potassium, at any rate under certain conditions, as chromate of potassium. If, instead of taking the eutectic mixture, we take one in which there is an excess of the potassium chromate, the phenomena of consolidation are varied in the most interesting manner. Large yellow crystals and groups of crystals of potassium chromate are first formed and then the eutectic mixture consolidates. In the microscopic preparations the structure is porphyritic, the eutectic mixture playing the rôle of ground-mass. We have now considered at sufficient length the general phenomena of solution and fusion, and we may summarize the more important results as follows:—

1st.—All homogeneous liquid masses containing two or more definite compounds may be regarded as solutions.

2nd.—A solution is said to be saturated with any particular compound when a change in temperature (generally a lowering) causes the crystallization of that compound.

3rd.—A solution is said to be "super-saturated" for any particular compound when the temperature is lower than that at which the compound would separate if crystals of that compound were present.

4th.—A liquid is said to be over-cooled when its temperature is lower than that of its normal consolidating point. Over-cooling is, therefore, analogous to super-saturation.

5th.—If the different compounds in a solution are present in eutectic proportions the mass will consolidate at a fixed temperature.

6th.—If such a mass crystallizes, in the act of solidifying, two or more compounds will be formed, and it is probable that these compounds may form ultra-microscopic, microscopic or macroscopic aggregates.

7th.—When the compounds in a solution are not present in eutectic proportions the order of consolidation, in certain cases, depends upon the relative proportions of the constituents —not upon their relative fusibilities. Thus, in a solution containing A and B, the order of crystallization may depend on whether A or B is in excess of the eutectic proportion.

Mixtures of fused silicates, such as those from which artificial glasses, slags, and igneous rocks are formed, may be regarded as solutions. This was maintained long ago by BUNSEN as regards the igneous rocks and by BENRATH and others as regards artificial glasses. Prof. LAGORIO[1] has recently discussed the phenomena of igneous rocks from this point of view in a paper from which we shall frequently quote in what follows. Silicate-solutions differ from aqueous solutions in the readiness with which they form an amorphous glass when cooled rapidly. This appears to be connected with the fact that they may be readily over-cooled, and that when in this state they are highly viscous, so that a rapid approach of the molecules is prevented. The melting point of a glass is lower than that of the same substance in a crystalline condition. A glass, therefore, results from the solidification of an over-cooled liquid.

The common varieties of artificial glass are amorphous mixtures of various silicates, especially those of the alkalies and alkaline earths. They are formed by fusing together certain constituents such as quartz, chalk, and sulphates or carbonates of soda or potash. At the high temperature of the glass-furnace silicic acid displaces sulphuric and carbonic acids, thus liberating sulphuric anhydride (decomposed at a red heat into sulphur dioxide and oxygen) and carbonic anhydride.[2] When the ingredients are mixed in suitable proportions the fused mass consolidates as an amorphous glass. All kinds of glass may be devitrified, that is, may be converted into a crystalline aggregate. This is done by maintaining the glass for a long time at a temperature sufficient to soften the glass but not sufficient to melt it. Different glasses behave very differently when subjected to the conditions which determine devitrification. Some are devitrified readily, others with difficulty. The potash-glasses are the most obstinate in resisting devitrification. A consideration of the phenomena of glass-making leads to the following conclusions according to LAGORIO. Silicate-solutions are not easily saturated with silicates containing potassium and aluminium or with silica itself. They are more readily saturated with sodium silicates and still more readily with silicates of lime and magnesia. In other words silicates of the alkaline earths separate out most readily from silicate-solutions; then follow sodium-silicates and last of all come potassium-silicates and free quartz.

These facts correspond very closely with what is known with regard to

(1) Ueber die Natur der Glasbasis sowie der Krystallizationsvorgänge im eruptiven Magmen. T.M.M., Band VIII., p. 421.

(2) Compare this with the fact that sulphurous and carbonic acids are frequently exhaled in connection with volcanic action.

the crystallization of minerals in igneous rocks. Seeing that the order of separation of minerals in igneous magmas depends not only upon the characters of minerals (*e.g.*, fusibility and composition), but also on the composition of the magma it is impossible to draw up a table which will express the order of consolidation in all cases. The following is the general order according to LAGORIO:—Oxides, Fe-silicates, Mg-silicates, Fe + Mg-, Mg + Ca-, Mg + K- (or Fe + K-), Ca-, Ca + Na-, Na-, and lastly K-silicates. Free SiO_2 may crystallize out before, after or simultaneously with K-silicates.

The general subject of the crystallization of minerals in igneous magmas has been discussed in Chapters II. and III. The conclusions there laid down have been confirmed and extended by LAGORIO in the important paper already referred to, which has appeared since those chapters were written. We will now quote some additional facts which have been established by LAGORIO. First as regards the acid rocks.

	I. (Glass).	II. (Spherulite).	III. (Glass).	IV. (Spherulite Border).	V. (Spherulite Nucleus).
SiO_2	72·35	73·21	73·05	74·52	73·42
Al_2O_3	13·97	12·90	14·67	12·97	14·29
Fe_2O_3	1·29	2·10	0·89	2·02	1·01
CaO	0·72	0·88	0·97	0·92	1·00
MgO	0·46	0·27	0·26	0·25	0·43
K_2O	5·38	4·75	5·11	4·53	3·19
Na_2O	3·58	4·83	3·99	4·26	5·61
Loss	1·37	1·04	0·91	0·83	0·84
	99·12	99·98	99·85	100·30	99·79
Sp. Gr.	2·1328	2·1121	2·2105	2·0891	2·5232

	VI. (Glass).	VII. (Spherulite).	VIII. (Glass).	IX. (Spherulite).	X. (Felspar).
SiO_2	72·70	74·36	74·59	76·48	62·14
Al_2O_3	13·79	14·46	12·88	12·06	22·30
Fe_2O_3	1·01	1·62	0·80	0·95	tr.
CaO	2·07	1·49	0·76	0·64	3·29
MgO	0·65	0·44	0·30	0·39	tr.
K_2O	4·33	1·49	5·35	3·78	1·69
Na_2O	4·93	6·11	3·30	4·89	10·58
Loss	1·10	0·57	1·03	0·77	0·20
	100·58	100·54	99·01	99·96	100·20
Sp. Gr.	2·359	2·4080	2·3235	2·4005	2·647

I. Glassy base of a spherulitic obsidian from Lipari. The order of consolidation of constituents in this rock was, 1st, belonites and magnetite, 2nd, spherulites.

II. Spherulite from the same rock. The spherulites give a black cross.

III. Glassy base of a spherulitic obsidian from Teneriffe. Order of consolidation of constituents, 1st, microlites and trichites, 2nd, spherulites.

IV. External portion of spherulite from the same rock.

V. Internal portion of spherulite from the same rock.

VI. Glass of spherulitic obsidian from Cerro del Quiuche, Quito. Probable order of consolidation in the rock, 1st, opaque grains and belonites, 2nd, felspar, 3rd, quartz, 4th, spherulites.

VII. Spherulite from the same rock.

VIII. Glass of a spherulitic rock from Ecuador. Order of consolidation of constituents in the rock 1st, trichites, belonites and magnetite, 2nd, striated felspar (anorthoclase), 3rd, spherulites.

IX. Spherulite from the same rock. Shows a feeble cross in polarized light.

X. Felspar (anorthoclase) out of same rock. Extinction on P + 3°30′ on M + 7°15′.

A consideration of these and other analyses given by LAGORIO points to the conclusion that in a magma rich in silica and the alkalies and poor in lime and magnesia, the Na_2O-silicates tend to separate out in preference to the K_2O-silicates. Thus the spherulites are richer in soda than the glass. Moreover, the felspar in the rock from Ecuador is richer in soda than the spherulite in the same rock; it is essentially a soda-felspar. It follows also from LAGORIO's analyses that the spherulites contain a slightly higher silica-percentage. This, however, may be simply a consequence of the former fact for Na_2O-silicates contain more silica than the corresponding K_2O-silicates, because the atomic weight of Na is lower than that of K. K_2O-silicates can separate out only when they are present in great quantity. According to LAGORIO, the molecular ratio of $K_2O : Na_2O$ must be at least as high as 2 : 1 before sanidine can form, and even then it contains a considerable amount of Na_2O.

As regards the intermediate rocks, LAGORIO's researches merely confirm the results already given in Chapter II, as may be seen from the following analyses.

	I. (Rock).	II. (Ground-mass)	III. (Felspar).	IV. (Rock.)	V. (Base).	VI. (Felspar).
SiO_2 ...	68·32	74·76	56·53	67·30	72·44	62·21
Al_2O_3 ...	19·61	13·66	26·59	20·75	16·28	19·29
Fe_2O_3 ...		2·36	1·05			1·08
CaO ...	4·24	2·17	9·60	2·63	0·59	1·18
MgO ...	1·95	0·53	—	1·05	0·20	0·05
K_2O ...	1·45	2·05	0·80	4·60	6·49	12·00
Na_2O ...	4·06	2·96	6·11	2·75	2·12	2·54
Loss ...	0·54	0·82	0·02	0·34	1·35	1·05
	100·17	99·31	100·70	99·42	99·47	99·40
Sp. Gr.	2·7651	2·6186	2·6850	2·5410	2·2540	2·5673

	VII. (Rock).	VIII. (Base).	IX. (Felspar).	X. (Rock).	XI. (Base).	XII. (Felpsar).
SiO_2 ...	62·54	70·19	55·42	57·76	65·05	53·95
Al_2O_3 ...	23·56	17·19	28·01	18·39	17·60	27·45
Fe_2O_3 ...			1·09	7·51	3·10	1·09
CaO ...	4·75	2·50	9·12	6·21	3·58	11·48
MgO ...	1·15	0·53	tr.	3·34	1·05	tr.
K_2O ...	2·43	3·89	0·79	2·61	4·16	0·79
Na_2O ...	3·16	3·30	5·10	3·63	3·54	4·51
Loss ...	1·75	2·31	0·52	0·94	1·56	0·48
	99·34	99·91	100·05	100·39	99·64	99·75
Sp. Gr.	2·6941	2·4140	2·6890	2·6640	2·3757	2·6900

I. Dacite from Mojanda, Quito. Order of separation:—magnetite and apatite, hornblende, plagioclase, quartz, hornblende-microlites, felspar and quartz (?) of the ground-mass. The presence of base is doubtful.

II. Ground-mass of the above rock.

III. Zonal plagioclase from the above rock. Composition lies between Ab_4, An_3 and Ab_1, An_1. Extinction on M – 12; on P – 3°.

IV. Trachyte, Mte. Amiata, Tuscany. Order of separation:—magnetite and apatite, augite, mica, plagioclase, sanidine, microlites of the ground-mass.

V. Glassy globulitic base of the above rock. Contains pores in which tridymite occurs.

VI. Sanidine from the above rock. The sanidine separated after the augite, mica and plagioclase when the molten portion of the rock had the following composition according to Lagorio: SiO_2 69·88; $Al_2O_3+Fe_2O_3$, 17·30; CaO 0·71; K_2O 7·78; Na_2O 2·22.(1) The ratio of K_2O : Na_2O is therefore 2·3 : 1, and that of K_2O+Na_2O : SiO_2, 1 : 9·82.

VII. Andesite from Hliniker Thal, Hungary. Order of separation:—magnetite and apatite, mica, hornblende, augite, plagioclase, spherulitic bodies in the base.

VIII. Isotropic base of the above.

IX. Plagioclase of the above. Ab_1, An_1.

X. Vitro-andesite. Block ejected from Merapi, Java. Order of separation:—magnetite and apatite, augite, plagioclase; then magnetite, augite and felspar-microlites in the base.

XI. Glassy base of the above.

XII. Plagioclase of the above, Ab_3, An_4.

These analyses all point to the conclusion that the effect of progressive crystallization in an andesitic magma is to increase the percentages of silica and alkalies, especially potash, and to diminish the percentages of lime, iron and magnesia in the mother liquor. In short, the mother liquor approximates in composition to a mixture of quartz and orthoclase.

Let us turn now to the basic rocks.

	I. (Rock).	II. (Glass).	III. (Rock).	IV. (Glass).	V. (Rock).	VI. (Glass).
SiO_2 ...	52·87	52·68	44·27	44·87	40·48	40·64
Al_2O_3 ...	16·36	18·28	29 82	33·35	8·93	34·78
Fe_2O_3 ...	10·87	9·43			20·05	
CaO ...	7·94	8·04	11·69	6·51	13·03	7·25
MgO ...	5·23	4·68	5·83	2·50	11·12	5·15
K_2O ...	0·96	1·15	1·94	3·78	1·26	3·50
Na_2O ...	3·64	3·86	3·29	5·18	2·05	3·04
H_2O ...	1·22	1·02	2·51	3·12	3·37	5·17
	99·09	99·14	99·35	99·31	100·29	99·53
Sp. Gr.	2·7931	2·7730	2·8611	—	2·9310	—

I. Vitro-basalt from Schwarzenfels, Rhön. Order of separation:—olivine, augite, plagioclase.

II. Glassy base of the above rock. The ratio of K_2O : Na_2O is slightly greater in the glass than in the rock; 1 : 5·2 as against 1 : 6.

III. Dolerite, Mont Dore. Order of separation:—magnetite and apatite, olivine, augite, plagioclase (bytownite).

IV. Glassy base of same rock. In glass K_2O : Na_2O = 1 : 2; in rock K_2O : Na_2O = 1 : 2·5.

V. Limburgite, Kaiserstuhl. Order of separation: magnetite, hyalosiderite, augite, microlites of the base.

VI. Glassy base of the same rock. K_2O : Na_2O = 1 : 1·3 in glass and 1 · 1·25 in rock.

(1) These numbers are not reckoned so as to express the percentage composition, but only the relations of the different constituents.

It appears from these analyses that there is no very marked difference between the composition of the rock and of the glass in the basic rocks. In every case, however, we notice a slight tendency of the K_2O-silicate to increase in the glass. The marked tendency of the potassium silicate to remain behind in the mother liquor lends support to LAGORIO'S opinion that such a silicate has a greater claim to be regarded as the solvent medium than any other compound. It is important, however, to note that the mother liquor of intermediate and acid rocks contains more silica than that required to form orthoclase. Neglecting the other constituents which may be regarded as having crystallized out, the ultimate residuum corresponds to a mixture of quartz and orthoclase. Let us now assume that a fused mixture of quartz and orthoclase will, on cooling, behave as a mixture of fused nitre and chromate of potassium. If the two substances are present in eutectic proportions they will consolidate simultaneously and, conversely, if they consolidate simultaneously they must be present in eutectic proportions. If they are not present in eutectic proportions the compound in excess will first crystallize out and then the eutectic mixture will consolidate.

Now in the body of this work we have shown that micro-pegmatite plays the rôle of ground-mass in many dioritic rocks, as for example in the so-called "syenites" of Charnwood Forest, in the augite-diorite of Carrock Fell; and sometimes also in the enstatite-diorite of Penmaenmawr (see Fig. 2, Plate XXXV.) Moreover, it plays a similar rôle in the granophyres of Ennerdale, Carrock, and the Western Isles of Scotland. Again, in the enstatite-diorite of Penmaenmawr micro-pegmatite forms segregation veins and nodules. Mr. COLE has described a similar occurrence of pegmatite in "Stanner Rock."[1] The matrix of many felsites which do not show a micro-pegmatitic structure agree in chemical composition with a mixture of quartz and felspar. If we accept the point of view here suggested we have a very satisfactory explanation of the fact that in the acid rocks the order of consolidation of quartz and felspar is not constant. When quartz is present in excess of the eutectic proportion it will be the first mineral to crystallize out; when orthoclase is present in excess it will be first formed. The hypothesis suggested above brings so many facts into relation with each other that, notwithstanding its inability to explain all the facts, the present writer is disposed to attach some importance to it. If pegmatite (HAUY), whenever it occurs in an igneous rock, is an eutectic mixture in GUTHRIE'S sense, then it should have a constant composition.

To determine the composition of pegmatite the present writer has analysed a portion of a specimen, given to him by Mr. COLE, from a vein in the diabase of Stanner rock, near Kington. Microscopic examination shows that the specimen consists of quartz and felspar intergrown so as to form a very fine variety of graphic granite, verging on micro-

(1) G.M., Decade III., Vol. III. (1886), p. 220.

pegmatite, together with epidote, which is distributed along cracks, and is evidently, therefore, a secondary mineral.

	Rock.		*Felspar.*		*Epidote.*[1]		*Remainder.*
SiO_2	73·8	...	36·22	...	3·55	..	34.03
Al_2O_3	12·9	...	10·32	...	2·39	...	·19
Fe_2O_3	1·0	...	—	...	1·00	...	—
CaO	2·2	...	—	...	2·20	...	—
MgO	tr.	...	—	...	—	.	—
K_2O	8·4	..	9·1	...	—	...	—
Na_2O	·7						
H_2O	·4	...	—	...	·18	...	·22
	99·4		55·64		9·32		

The composition of the rock in minerals is, therefore, as follows :—

Felspar	55·64
Quartz	34·03
Epidote	9·32
	98·99

Neglecting the epidote the composition of the pegmatite is :—

Felspar	62·05
Quartz	37·95
	100·00

If micro-pegmatite is an eutectic compound these figures represent approximately its mineralogical composition.

The spherulites in many of the acid rocks probably answer in composition to micro-pegmatite. In the last edition of his work ROSENBUSCH[2] suggests that they may be formed of a definite chemical compound—microfelsite—in which the ratio of alkalies to alumina is the same as in the felspars, the silica being in excess of that required to form an alkali-felspar. The present writer is inclined to regard these spherulites as due to the simultaneous crystallization of quartz and felspar, and as analogous to the spherulites formed during the consolidation of the eutectic mixture of nitre and nitrate of lead. If this be correct then the spherulites in question are simply special modifications of the pseudo-spherulites and micropegmatite.

SORET'S principle may have important geological applications. Thus, as LAGORIO points out, it will furnish a plausible explanation of the fact that certain dykes are glassy in their central portions, instead of at their margins as is more frequently the case. Suppose a mass of molten material to be injected into a fissure and to remain stagnant for a considerable length of time, the mass will be cooled at the margins, and the compounds with which the solution is most nearly saturated will accu-

(1) The epidote is calculated from TSCHERMAK'S formulæ on the assumption that the lime and iron are wholly present in this mineral. The error involved in this assumption is too slight to seriously affect the result as regards the relative proportion of felspar and quartz.

(2) Mik. Phy. d. mass. Gesteine, p. 389.

mulate in the marginal portions, leaving the centre richer in those which play the rôle of solvent medium. An example of this kind is furnished by the Eskdale dyke (see *ante*, page 195), and it is worthy of note that the difference in composition between the glass and the marginal portion is exactly what is required by theory.

SORET'S principle may also be applicable to plutonic rocks. Homogeneous molten masses may become heterogeneous by diffusion of certain constituents during cooling. Thus an intermediate magma may become differentiated into a basic and an acid magma.

An interesting question arises as to whether super-saturation or over-cooling have taken place in igneous magmas which have subsequently consolidated as crystalline rocks. LAGORIO is of opinion that the porphyritic crystals in igneous rocks have grown rapidly in super-saturated solutions, and that the granitic structure in plutonic rocks is the result of rapid crystallization in over-cooled magmas under pressure. A prolonged discussion of these points in the present imperfect state of our knowledge seems scarcely desirable in a work like the present. As regards the latter point we may, however, remark that over-cooled silicate-solutions under ordinary pressures are so viscous that anything like rapid crystallization is impossible. Such solutions consolidate as glasses.

Any account of the facts which throw light on the conditions under which igneous rocks are formed would be incomplete without a description of the remarkable synthetic experiments of Messrs. FOUQUÉ and LEVY. The first attempts to reproduce crystalline rocks by pure igneous fusion were made by JAMES HALL[1] and GREGORY WATT[2] towards the close of the last century and during the commencement of the present one. They showed that if a basic igneous rock be melted and then slowly cooled it will assume a more or less crystalline structure. HALL, moreover, established the important fact that the fusing point of the artificial glass, formed by melting an igneous rock, is lower than the fusing point of the original crystalline rock or of the artificial crystalline product formed by the slow cooling of the molten mass. The imperfect methods available for the purpose of determining the precise character of the artificial products prevented these early observers from deriving the full advantage from their most important experiments.

Previous to the experiments of Messrs. FOUQUÉ and LÉVY it was very generally believed that igneous rocks were not and could not be produced by pure igneous fusion. This view had been insisted upon by many observers, including DELESSE, DAUBREE and SORBY.[3] It was held that aqueous vapour played an important part in promoting the development of crystals, even in volcanic rocks. The experiments referred to were made with a gas furnace and a forced blast. By varying the arrangement of the parts and the supply of air and gas a considerable range of

(1) Trans. Roy. Soc. Edin., Vol. V. (1805).
(2) Phil. Trans., (1804), p. 279.
(3) Geol. Mag., Decade II., Vol. VII. (1880), p. 468.

temperature could be obtained. The authors describe four different arrangements which gave a series of decreasing temperatures.

1st Arrangement.—In this arrangement the temperature obtained was very near the fusing point of platinum. Olivine, leucite and anorthite could be reduced to a viscous mass which would consolidate as an amorphous glass.

2nd Arrangement.—Iron and steel fused easily; also the felspars (except anorthite) and the bisilicates, augite, enstatite, &c.

3rd Arrangement.—Steel only became softened, but copper fused easily. This represents the limit of fusion of labradorite and oligoclase; pyroxene and nepheline may be completely fused.

4th Arrangement.—Copper fused with difficulty.

The materials employed in the experiments were either the chemical constituents, obtained by precipitation, or the powder of the natural minerals. On fusing the materials with arrangement No. 1 and allowing the fused mass to cool rapidly a perfectly homogeneous glass was obtained. It was found, however, that very rapid cooling was necessary to prevent the crystallization of augite, enstatite, melilite and nepheline. The felspars on the contrary only crystallize after prolonged cooling. These facts agree with what has been stated above as to the readiness with which Fe-, Mg- and Ca-silicates saturate silicate magmas. As regards the order of separation of minerals in the synthetic experiments the authors state that leucite, anorthite, olivine, magnetite and picotite separate out with the arrangement No. 2; labradorite, oligoclase, augite, enstatite, hypersthene, magnetite and picotite with No. 3; and the same minerals with nepheline, melilite and melanite with arrangement No. 4, that is at a bright red heat. We will now describe some of the rocks which have been synthetically produced.

(1) Oligoclase-augite rock (andesite without porphyritic crystals). Obtained by fusing four parts of oligoclase with one of augite. Cooling prolonged for four days with arrangement No. 3. Microlites of oligoclase measuring on the average ·25 mm. × ·015 and twinned on the albite plan; microlites of augite of a pale yellow colour (·06 × ·02) distributed without order through the mass; also a few octahedra of magnetite developed at the expense of the iron in the original augite.

(2) Labradorite-augite rock. Obtained by fusing three parts of labradorite with one of augite. Cooling prolonged over three days with arrangement No. 3. Microlites of labradorite (·25 × ·025) twinned on the albite plan; microlites of yellowish brown augite (·05 × ·025) possessing cleavages and transverse fractures similar to those of the natural rocks; also octahedra of magnetite.

A rock similar to the above but containing in addition a few long prisms of melilite was obtained by fusing the scapolite-hornblende rock from Bamle.

(3) Olivine-basalt. Obtained from a black glass answering to the composition, six of olivine, two of augite and six of labradorite. The

cooling was divided into two stages. The first stage (arrangement No. 2) was prolonged for forty-eight hours; the second stage (arrangement No. 4) for the same time. During the first stage olivine crystals were formed measuring on the average ·5 mm. × ·2. These were similar in form and optical characters to those occurring in the natural basalts. Magnetite and picotite also crystallized out in octahedra (·02 mm.) during this stage. During the second stage microlites of labradorite (·15 mm. × ·03 mm.) elongated in the direction of the edge 001 : 010, twinned according to the albite plan and giving a maximum extinction of 30° were formed together with short microlites (·05 × ·025) of augite and some magnetite and picotite (·005). A small quantity of matter remained in the amorphous condition.

(4) Nepheline-augite rock. A mixture of three parts of nepheline and 1·3 of augite gave, after cooling for two days, under the arrangement No. 4, an association of nepheline and augite. The nepheline occurred in short hexagonal prisms (·02 mm.), the augite in greenish yellow crystals (·01 × ·004). There were also some larger microlites of augite.

(5) Leucite-augite rock. A mixture composed of nine parts of leucite and one of augite maintained for three days under the arrangement No. 2 gave an association of leucite (mean diameter ·06), greenish pyroxene (·025 × ·003), magnetite (·005), and glass of the same colour as the augite.

(6) Leucite-labradorite-augite rock (leucotephrite). A mixture of silica, alumina, potash, soda, magnesia, lime and oxide of iron representing one part of augite, four of labradorite and eight of leucite was fused and then maintained for two days under the arrangement No. 2, and for a corresponding period under the arrangement No. 4. The result was a mass composed of leucite crystals (mean diameter ·35), microlites of labradorite (·05 × ·02), microlites of augite (·025 × ·005) and magnetite. Leucite and magnetite (·01) were formed during the first stage, the remaining constituents together with magnetite (·003) during the second stage.

(7) Olivine-enstatite-augite-picotite rock (lherzolite). This association was obtained by prolonged cooling. The artificial product differed from the natural rock in having the picotite in octahedra—not in irregular plates. Moreover, glass-inclusions were more abundant in the artificial than in the natural rock.

(8) Anorthite-augite rock with ophitic structure. Obtained by fusing together one part of anorthite and two of augite, or one part of anorthite to one of augite.

During the first stage the mixture was maintained under the arrangement No. 2 for four days when the anorthite crystallized out; during the second stage it was maintained for the same length of time under the arrangement No. 3 or No. 4, when the augite crystallized out.

Arrangement No. 3 produced the structure throughout the mass; arrangement No. 4 produced it only in the parts most strongly heated, the augite in other parts being in the condition of microlites. Hence

one and the same section may show both the microlitic and ophitic structures. The ophitic structure could not be perfectly developed with labradorite.

It appears, therefore, from the above experiments that many igneous rocks can be produced by pure igneous fusion without the intervention of water in any kind of way. Not only are the positive results obtained by Messrs. FOUQUÉ and LÉVY of the greatest value, but their negative results are also of great interest. All attempts to produce rocks containing quartz, orthoclase, albite, white mica, black mica and hornblende have failed. A mixture of 4 parts of microcline and 4·8 of biotite yielded on cooling a crystalline mass composed of leucite, olivine, melilite and magnetite. Fused wernerite crystallized on cooling as labradorite, and a mixture of wernerite and hornblende gave rise to a labradorite-augite rock. A mixture of oligoclase and hornblende gave rise to an oligoclase-augite rock (augite-andesite).

The association of orthoclase and quartz, so characteristic of many igneous rocks, has never been produced by pure igneous fusion, but it has been obtained by heating the constituents of these minerals in a closed vessel in the presence of alkaline water.

In concluding this portion of our subject let us take a general and more or less speculative view of the phenomena attending the consolidation of igneous magmas. When the consolidation is effected under what may be termed plutonic conditions, that is, under a pressure vastly in excess of that due to the atmosphere, a holo-crystalline rock of granitic structure is produced. The first-formed constituents are idiomorphic, but the later constituents, which generally make up the main mass of the rock (*e.g.*, quartz and orthoclase in granite; plagioclase and diallage in gabbro) are allotriomorphic. Plutonic masses may be homogeneous, that is, the different constituents may be mixed in fairly uniform proportions; or they may be heterogeneous, that is, the different constituents may be mixed in different proportions in different parts. This heterogeneity is represented by the so-called concretionary patches (diorite in granite) by contemporaneous veins (granite and granophyre in diorite, eurite in granite, troctolite in peridotite) and sometimes by a gradual passage from one kind of rock to another in the same mass (gabbro or augite-diorite into granophyre, as in Carrock Fell). In some cases one kind of plutonic rock, such as granite, is seen to vein another kind of rock such as diorite in the most intricate manner. Such cases may be regarded as exaggerated instances of contemporaneous veins. The rock which occurs as veins is necessarily of later date than the rock in which the veins occur, but the difference in point of time is probably not great. Both rocks belong to the same phase of plutonic action.

Now such cases of heterogeneity in plutonic masses as those referred to may be due to SORET'S principle; or to progressive crystallization accompanied by a separation of the first-formed crystals;

or possibly to causes of which we are at present totally ignorant. The present relation of the different parts is probably in many cases the result of movements taking place after the differentiation has been effected. The fact that plutonic masses are often heterogeneous is of great importance as bearing on the origin of those banded crystalline rocks which are identical with plutonic rocks in composition.(1)

Plutonic magmas may, by the action of earth-stresses or by the action of imprisoned vapours, be injected into the surrounding and overlying rocks. Under these circumstances they will follow planes of least resistance and take the form of dykes, sheets or laccolites. The planes of least resistance may be faults, joints or planes of stratification. Volcanic eruptions take place when a communication is established between the plutonic masses and the surface of the earth. The ultimate form taken by the ejected material will depend on the character of the eruption. The molten matter which reaches the surface is generally charged with crystals. These crystals have been developed in the molten mass either before or during the act of eruption. Very often their central portions have been formed under plutonic conditions and their peripheral portions during the act of ejection. They constitute the porphyritic constituents of the volcanic rocks, and as illustrations we may mention the quartz and orthoclase (sanidine) of the felsites and liparites, the plagioclase and pyroxene of the andesites, and the plagioclase, olivine and pyroxene of certain basalts and dolerites. Such crystals frequently occur in groups, and when this is the case the internal relations of the crystals accord with the view that they have been developed under plutonic conditions—the individuals of a group are often allotriomorphic internally and idiomorphic externally. This feature is well illustrated by the bytownite-aggregates in the Tynemouth dyke and the labradorite-aggregates in the Cheviot andesite (see Fig. 1, Plate XXXVI.)

The porphyritic crystals of the volcanic rocks frequently show a zonal structure and the material of successive zones presents different chemical and optical characters. This zonal structure is best seen in the lime-soda felspars and in the augites. It is due to isomorphous replacements and to change in the composition of the magma during consolidation. As a consequence of this zonal structure it follows that the analysis of one zoned individual does not represent the composition of any portion of that individual —it is merely, as ROSENBUSCH says, a kind of bulk analysis. The porphyritic crystals frequently give evidence of corrosion and sometimes also of crystalline growth having taken place after corrosion. The corrosion may be due to physical or chemical changes during consolidation. Mere relief of pressure may, as LAGORIO points out, have the effect of corroding crystals; for, by SORBY'S principle,

(1) See TEALL, on the Origin of certain Banded Gneisses, G.M., Decade III., Vol. IV., p. 484.

relief of pressure acts in the same way as increase of temperature so far as crystallization in igneous magmas is concerned. Again, corrosion may be due to a change in the composition of the magma caused by the separation of minerals of a different composition from the one under consideration, or by the addition of other material to the liquid mass. When a period of crystal-growth follows a period of corrosion the new material may have a zonal structure which stands in relation to the corroded outlines.

Crystals formed under plutonic conditions may be corroded and even destroyed under volcanic conditions. This important point is well illustrated by the minerals, hornblende and biotite. These minerals have never yet been synthetically produced by pure igneous fusion under ordinary pressure. So far as igneous magmas are concerned they appear to be in general of plutonic origin.(1) When they occur in volcanic rocks they are frequently surrounded by a black border composed of magnetite and augite. In many cases the form only of the original mineral is preserved and we may, therefore, safely conclude that in many other cases all traces of original hornblende and biotite have disappeared.

The mechanical actions accompanying the eruption of igneous material often produce important effects on the previously formed crystals, breaking them and fracturing them in various ways.

So far we have been referring to actions which may take place before the actual appearance of the molten matter at the surface. After eruption the lava flows over the surface; the ultimate form of the rock-mass depending on the fluidity of the lava and the configuration of the district. Any want of homogeneity in the original magma will produce banded or linear structures in the consolidated mass. The material which was molten at the time of eruption may contribute somewhat to the enlargement of the pre-existing crystals, but the bulk of it consolidates to form the ground-mass of the rock. The ultimate character of the ground-mass depends on the extent to which crystallization is carried on after eruption. Every gradation may be observed between a rock with a vitreous ground-mass in which only crystallites or spherulites have been developed, to one in which complete crystallization has taken place. The effect of progressive crystallization on the composition of the residual glass has been so frequently referred to that nothing further need be said on this subject. As soon as final solidification has taken place the rock is formed and liable to be modified by the agencies which we shall refer to in the next chapter.

The molten mass is frequently charged with water and other volatile substances at the time of the eruption. In the case of a paroxysmal eruption, such as that of Krakatoa, the water is present

(1) Lacorio mentions the occurrence of hornblende-needles (5 mm. × ·5 to 1 mm.) in the pores of a leucite-tephrite from Vesuvius (lava of 1822). The needles lie free in the pores and do not occur in the rock. T.M.M., Neue Folge, Band VIII., p. 523.

in great quantities, and, by its violent escape, blows the lava into the condition of spray. The crystals are thus ejected in a whole or fragmentary state while the molten mass takes the form of glass. Owing to the fact that bubbles are developed in immense quantities at the time of eruption, the glassy matter frequently takes the form of thin and more or less curved plates separating the different bubbles. The external surfaces of the fine, glassy dust are concave, with cusp-like projections between contiguous concavities. When the glassy mass merely froths up in consequence of the development of bubbles, but is not blown into the condition of spray, pumice is formed. The glassy dust above referred to precisely resembles disintegrated pumice.

CHAPTER XIV.

The Metamorphosis and Destruction of Igneous Rocks.

GEOLOGICAL history is a history of the formation, metamorphosis and destruction of rocks. An igneous rock is no sooner formed than it is liable to be modified or destroyed by various agencies. In the previous chapters we have frequently had occasion to refer to the rock-modifying and rock-destroying agencies so far as particular rocks are concerned. All that remains to be done in the present chapter is to treat of the effects of these agencies from a somewhat general point of view. For convenience of reference we may roughly classify the more important of them as follows :—

Surface Agencies.

1. Thermal waters, fumarole- and solfataric action.
2. Normal surface agencies depending on change of temperature, rain-water more or less charged with carbonic acid, organic acids derived from the soil, oxygen, &c.

Deep-Seated Agencies.

1. Percolating waters ; effects of gaseous exhalations—deep-seated fumarole-action—&c.
2. Contact-metamorphism.
3. Dynamic metamorphism.[1]

Steam, sulphuretted hydrogen, hydrochloric acid and other gaseous substances are evolved during the final stages of volcanic action. Sulphuretted hydrogen may become oxidized by contact with the air ; thus giving rise to sulphurous and sulphuric acids. These gaseous exhalations which are especially marked in fumaroles and solfataras often produce important effects upon the volcanic rocks. Thus, the well-known solfatara near

(1) Of the various expressions—pressure-metamorphism, regional metamorphism, mechanical metamorphism and dynamic metamorphism—which have been applied to the change due to the deformation of rock-masses, the last appears to be the most appropriate. It has been used in the later portions of this work in preference to the expression regional metamorphism which was adopted in the introduction. The objection to the first expression is that pressure alone produces no effect on rocks—work must be done upon the rocks before change takes place ; the objection to the second is that the action is sometimes local ; and the objection to the third is that it conveys the idea that chemical changes do not take place. The expression dynamic metamorphism is free from all these objections. It emphasizes the fact that work is done upon the rocks in the act of metamorphism, it does not exclude molecular changes by implication and it is equally applicable to local and regional effects.

Naples gives off steam and sulphur-compounds which decompose the trachytic rock and lead to the formation of gypsum and alum. Pyrites occurs as a secondary constituent of many volcanic rocks. It may be formed by the action of sulphuretted hydrogen on the iron-compounds present in the original rock.

Thermal waters charged with various substances in solution are common in volcanic districts. These are potent agents in rock-metamorphosis. The water of the Great Geyser of Iceland contains 2·448 cubic centimetres of sulphuretted hydrogen per litre according to DES CLOISEAUX, and leaves on evaporation 1225 milligrammes of solid matter per litre according to M. DAMOUR. The composition of the water of the Great Geyser has been studied by SANDBERGER and DAMOUR, with the following results:—One thousand parts of water contain (A) according to SANDBERGER and (B) according to DAMOUR[1]:—

		A.		B.
SiO_2	...	0·5097	...	0·5190
Na_2CO_3	...	0·1939	...	0·2567
Na_2SO_4	...	0·1070	...	0·1342
K_2SO_4	...	0·0475	...	0·0180
$MgSO_4$	...	0·0042	...	0·0091
NaCl	...	0·2521	...	0·2379

It seems probable, as DAMOUR has pointed out, that the silica was originally in combination with the bases, soda and potash, in the form of alkaline silicates, and that these silicates have been derived from the subterranean decomposition of felspathic rocks. If so, it follows that a process of subterranean kaolinization must be going on. At present, however, we are not concerned with the subterranean effects produced by percolating waters, but with the changes which thermal waters charged with silica and other substances may produce on igneous rocks at or near the surface. Assuming that the geyser-water in the first instance contained alkaline silicates then we see that these silicates are decomposed by the action of hydrochloric, carbonic and sulphuric acids—the silica is liberated and carbonates, sulphates and chlorides of the alkalies are formed. The water of the Great Geyser deposits a siliceous sinter (geyserite), having the following composition according to FORCHAMMER:—

SiO_2	...	84·43
Al_2O_3	...	3·07
Fe_2O_3	...	1·91
CaO	...	0·70
MgO	...	1·06
K_2O (Na_2O)	...	·92
H_2O & C	...	7·88
		99·97

Now if water, having the composition of that of the Great Geyser, percolates through porous rocks it will deposit a portion of its silica in

(1) Quoted from ROTH's Allgemeine und Chemische Geologie, p. 592.

the veins and cavities. In this way a volcanic rock may become impregnated with secondary silica in the form of hyalite, opal, chalcedony, quartz, to such an extent that its bulk analysis will give a totally erroneous impression as to its original composition. The andesites and porphyrites of the Cheviot district furnish interesting illustrations of silicification. The comparatively unaltered enstatite-andesite is traversed by veins of opal and chalcedony (see Fig. 1, Plate XXXVI.), while the amygdaloidal porphyrites are celebrated for their agates. In some cases the decomposition of a rock by solfataric or other action may precede its silicification. Professor BLAKE, has shown that portions of the Roche Castle Rock, Pembrokeshire, have been highly silicified, so that the porphyritic felspars are now represented by aggregates of quartz.(1) In such a case as this it is clear that the silicification has been preceded or accompanied by causes which have decomposed the original rock, perhaps an andesite or trachyte, and removed in a state of solution not only the alkalies, but also the comparatively insoluble alumina. The silicification of volcanic rocks by thermal waters originating in connection with volcanic action must naturally be associated in most cases with the formation of siliceous sinter. Mr. MARR'S suggestion,(2) therefore, that such masses of highly siliceous rock (97·5% of SiO_2) as those of Trefgarn were originally sinters is one which deserves most careful consideration.

As illustrating the importance of thermal waters, not only in introducing new minerals into rocks, but also in forming mineral veins, we may refer to the celebrated Steam Boat Springs of Nevada and the associated ore-deposits. According to Mr. G. F. BECKER(3) the waters of these springs are "now depositing gold, probably in the metallic state; sulphides of arsenic, antimony and mercury; sulphides or sulphosalts of silver, lead, copper and zinc; iron oxide and possibly also iron sulphides; manganese, nickel and cobalt compounds, with a variety of earthy minerals. The sulphides which are most abundant in the deposits are found in solution in the water itself, while the remaining metallic compounds occur in deposits from springs now active, or which have been active within a few years." Mr. PHILLIPS points out that these waters issue from cracks and that the walls of the cracks are lined, sometimes to a thickness of several feet, with incrustations of silica of various degrees of hydration containing hydrated ferric oxide and occasionally crystals of iron pyrites.(4)

Many igneous rocks, and especially those of basic composition, are often highly charged with zeolites. The classic researches of M. DAUBRÉE(5) on the formation of zeolites and other minerals in the Roman

(1) Q.J.G.S., Vol. XL, 1884, p. 308.

(2) See report of the discussion on Dr. BONNEY'S paper. Q.J.G.S., Vol. XLII., 1886, p. 363.

(3) Natural solutions of Cinnabar, Gold and associated sulphides. A.J.S., Vol. XXXIII. 1887, p. 199.

(4) Ore Deposits, 1884, p. 70.

(5) Études synthétiques de géologie expérimentale, Paris, 1879, p. 180.

concrete of PLOMBIÈRES render it almost certain that thermal waters are the agencies by which these minerals are formed in rocks. These springs issue from fissures in the granite, which fissures stand in relation to the mineral veins of the district. The temperature of the warmest of them does not exceed 70°. Those which have a temperature between 15° and 32° deposit a hydrous silicate of alumina allied to halloysite. The quantity of matter dissolved in these springs does not exceed 30 milligrammes per litre. Silicate of potash is the dominating constituent and fluoride of calcium also occurs. The waters were conducted by the Romans in channels formed of a concrete composed of fragments of brick and sandstone cemented by lime unmixed with sand. In the course of ages various minerals have been formed in the concrete, including apophyllite, chabasite, chriastianite, hyalite, opal, fluorite, calcite, arragonite, a hydrous magnesium carbonate and halloysite. Apophyllite, a non-aluminous zeolite containing calcium and potassium together with a small quantity of fluorine, is found only in the cement; chabasite, on the other hand, an aluminous zeolite, is found in the brick. This localization of the zeolites shows that they are formed in place by a re-action between the alkaline waters and the different constituents of the concrete. In the development of zeolites and the deposition of silica in this concrete by the action of thermal waters we evidently have illustrations of a process which must take place extensively in many volcanic districts. The basaltic rocks of the North of Ireland and West of Scotland are in many places charged with zeolites which probably owe their origin to causes similar to those above referred to.

We have now to refer to what may be called the normal weathering of igneous rocks. When subjected to the physical and chemical conditions which prevail at the surface of the earth igneous rocks are in a state of unstable equilibrium. They are liable to undergo decomposition and disintegration. The different constituents are of course very differently affected, but in order that a rock may be completely disintegrated it is only necessary that one of its principal constituents should be liable to decomposition. Of all rock-forming minerals the felspars are perhaps the most important. These are liable to undergo decomposition under the influence of surface agencies. The Brothers ROGERS, and many later observers, have shown that water charged with carbonic acid will decompose orthoclase and remove alkali and silica, together with a small quantity of alumina. DAUBRÉE has proved that prolonged trituration of orthoclase in pure water is accompanied by a decomposition of the mineral; the water taking up potassium silicate and becoming markedly alkaline. The weathering of felspar is accompanied by a diminution in the amount of the alkalies, alkaline earths and silica, and by an increase in the amount of water. The ultimate residual product in all cases is kaolin. In the lime-soda felspars carbonate of lime may be formed and when this is the case the rock will of course effervesce with acids. The process of decomposition above

referred to is generally termed "kaolinization;" it is important, however, to bear in mind that all cases of kaolinization are not due to simple surface decomposition. In speaking of the origin of the constituents of the water of the Great Geyser, we have already referred to a process of subterranean kaolinization, and we shall have again to refer to such a process in dealing with the different varieties of deep-seated metamorphism. Next in importance to the felspars are the ferro-magnesian minerals—the pyroxenes, hornblendes, olivines and dark micas. These are also liable to decomposition by ordinary surface-agencies.

Lime, which enters largely into the composition of many of these minerals, is readily removed in the form of carbonate. Magnesia is far less readily removed and often gives rise to the formation of hydrous silicates, such as serpentine, chlorite, &c. Iron may be either removed or deposited, according as the decomposition is effected under the influence of reducing or oxidizing conditions. Epidote frequently arises in connection with the decomposition of the ferro-magnesian constituents, or as a result of the reaction between the solutions thus formed and the constituents of the felspars. The ultimate products of the decomposition of the non-aluminous minerals are carbonates, ferric oxide and quartz. Iron ores become fully oxidized under the influence of atmospheric conditions. Quartz and muscovite are comparatively stable under these conditions, and are, therefore, removed by mechanical rather than chemical means. The minute accessory constituents, such as zircon, tourmaline, rutile and spinelle are also comparatively stable under atmospheric conditions, and owing to their small size are but little acted upon by the mechanical agencies by which the insoluble constituents of igneous rocks are removed and deposited. We accordingly find them in almost all deposits of fine sand and clay.

It appears, therefore, that igneous rocks may be decomposed and disintegrated by what we have called the normal surface-agencies. In many cases, however, the rocks have been more or less altered before being exposed at the surface by denudation; so that, in considering the causes of decomposition it is impossible to separate completely the effects of deep-seated agencies from those which operate directly on the surface. The plutonic rocks especially are often, as it were, prepared by the deep-seated agents of change for disintegration under surface conditions.

The solid matters which thermal springs bring to the surface furnish, as we have already seen, direct evidence of subterranean changes brought about by the percolation of water through the rock. As to the precise nature of these changes we are generally ignorant, but we may call attention to one or two instances of wide-spread alteration in igneous rocks which are almost certainly due to the cause referred to.

The Comstock Lode occurs in a region of highly-altered igneous rocks. It is difficult to define the area of alteration with anything like precision in consequence of the absence of well-defined boundaries,

According to Mr. BECKER[1] it extends for a distance of about four miles parallel to the direction of the lode, and about two miles at right angles to this direction. The lode itself lies on the western side of the decomposed area. The dominant rocks in this area are hornblende- and pyroxene-andesites and their holo-crystalline representatives. The alteration has affected more especially the ferro-magnesian constituents—augite, hornblende and mica. Chlorite has been extensively developed, and epidote has frequently been subsequently formed at the expense of the chlorite. Pyrite also occurs largely in the altered rocks. The felspars have been less affected than the ferro-magnesian constituents, but in extreme cases they also have lost their individuality. The widely-disseminated chlorite has often extended beyond the boundaries of the original ferro-magnesian constituents and penetrated into cracks and cavities in the more or less altered felspar. As a result of this the altered rocks have a greenstone-like aspect It is these altered rocks which constitute the "propylite" of VON RICHTOFEN and ZIRKEL. Mr. BECKER has shown that in the Washoe District propylite has no claim to be regarded as an independent rock. The name is one which has been applied to altered forms of different rocks. The chemical re-agents required to produce the changes which have taken place in the Washoe rocks are water, carbonic acid and sulphuretted hydrogen. A stream of water met with at a depth of over three thousand feet was found to be heavily charged with sulphuretted hydrogen and to possess a temperature of about 77°. Carbonic acid is also known to exist in the waters of the mine. The development of pyrites in the rocks is thus accounted for by the action of sulphuretted hydrogen.

An important question arises as to the connection between the lode itself and the area of decomposed igneous rock. Have the minerals or ores of the lode been derived from the surrounding rock? Mr. BECKER states that the unaltered rock (diabase) contains a noteworthy amount of the precious metals, which are found to occur mostly in the augite. The altered rock on the other hand contains only about half as much as the fresh rock. It is worthy of note that in the district of Schemnitz, in Hungary, we have also an association of mineral veins with the so-called propylite.

We have now to refer to cases of the deep-seated alteration which may reasonably be regarded as the effect of more powerful agencies than those already considered, and especially to a kind of plutonic fumarole- or solfataric action in which compounds of fluorine and boron play an important part. That such compounds are potent agents in decomposing granitic rocks and developing new minerals is rendered highly probable by many facts relating to the association of minerals in Cornwall and Devon; amongst which we may mention the conversion of granite in the neighbourhood of joint planes (see *ante*,

(1) Geology of Comstock Lode, Washington, 1882. p. 72.

p. 315) into greisen containing topaz; the occurrence of pseudomorphs of tourmaline and quartz, and of cassiterite and quartz after felspar; and the association of tourmaline with the masses of decomposed granite from which the kaolin is derived.

In 1824, LEOPOLD VON BUCH maintained that the deposits of kaolin in the neighbourhood of Halle were formed by the action of hydrofluoric acid on porphyry, and instanced the occurrence of fluorite in the decomposed mass as evidence of his view. M. DAUBRÉE[1] and Mr. COLLINS have applied the same theory to account for such masses of kaolinized granite as those occurring near St. Austell.

Mr. COLLINS has shown by experiment that kaolin may be produced by the action of hydrofluoric acid upon felspar. The proof, therefore, that kaolinization may be produced by subterranean as well as by surface agencies appears to be of a very satisfactory nature.

As a further illustration of the metamorphosis of igneous rocks by exhalations of compounds of fluorine and boron we may refer to the conversion of ordinary granite into shorl-rock, greisen, luxullianite and trowlesworthite. In all these cases the metamorphism is in all probability effected immediately after the formation of the rock by the fumarole-action which is a part of the phenomenon of intrusion. The case is similar to the alteration of a lava by the gases and vapours given off during the final stages of consolidation. It is, indeed, impossible, to separate by any hard and fast line the phenomena of consolidation and those of metamorphism. One part of a mass may be undergoing change while the adjacent parts are still unconsolidated.

As regards the alteration of igneous rocks by the intrusion of other rocks there is little to be said. The only case which has been worked out in anything like detail is the effect of granite on basic igneous rocks, and this has already been described at length.

We come now to the last type of deep-seated metamorphism, viz., that due to the earth-stresses.

Having regard to the great importance of the subject of dynamic metamorphism from a petrographical point of view, and to the fact that we are only beginning to recognize the structural and mineralogical characters which are to be attributed to it, a few general remarks on the nature and distribution of this kind of metamorphism will not be out of place. It must, however, be distinctly understood that these remarks are of a more or less speculative character. Our ideas on the subject are "en pleine évolution," and liable, therefore, to rapid modification and improvement as our knowledge increases.

The movements of elevation, depression, and lateral compression produced by the stresses which arise in the earth's crust have compelled rock-masses to assume forms other than those which they possessed in the first instance; that is immediately after their deposition and con-

(1) Géologie Expérimentale, p. 64.

solidation in the case of sedimentary rocks, and after their solidification in the case of igneous rocks.

Now the deformation of a rock-mass can only be produced by a relative movement of some or all of its parts. Two extreme cases may arise. The strain may be uniform throughout a considerable mass, in which case the microscopic character of the rocks will be altered; or the strain may be localized along special planes, in which case the parts enclosed between these different planes will retain their original characters. The first is a case of what may be termed plastic deformation, though it must not be supposed that the minerals of which rocks are composed are plastic in the sense that they can change their form without losing their individuality; the second is a case of what may be termed deformation by faulting. At first sight it appears as if these two types of deformation were radically distinct. This, however, is not so. There is in nature a most perfect gradation between plastic deformation and deformation by faulting.

In the sedimentary and igneous rocks which constitute the low-lying districts on the outskirts of a mountain-range we find deformation by faulting or gentle folding. The masses of rock which are enclosed between the fault-planes have moved as rigid bodies The differential movement is confined to the immediate neighbourhood of the fault-planes, and so also is the dynamic metamorphism. As the mountain range is approached the folds become sharper, the faults more numerous, and the size of those masses which have moved as rigid bodies becomes less and less. We observe, moreover, that the differential movement is often no longer confined to the fault-planes but affects the rocks to a greater or less distance from these planes. In such cases there is an increase in the amount of metamorphism (crushing of the constituents, development of new minerals, addition and subtraction of certain constituents) as the fault-plane is approached, and we are led to the important conclusion that the amount of metamorphism is in proportion to the deformation. Continuing our imaginary course in the same direction we notice that the folds become smaller and smaller, and the faults nearer and nearer together. Hand specimens will now illustrate the phenomena of folding and faulting as clearly as did large tracts of country in the outlying districts. At last both folding and faulting sink to microscopic dimensions, and it becomes impossible to discover, even with the aid of the microscope, a cubic millimeter of rock which has not been strained. Dynamic metamorphism which was localized at the fault-planes in the outlying districts has now become general—we are in an area of regional metamorphism. Argillaceous rocks have been converted into slates, phyllites, andalusite-schists; sandstones into quartzites and quartz-schists; felspathic sandstones into mica-schists; basic igneous rocks into hornblendic, actinolitic, and chloritic schists; acid igneous rocks into porphyroids, gneisses, and sometimes even into mica-schists. On reaching the central axis of the mountain range it is found to be composed of coarsely crystalline rocks of a plutonic

habit The zone of maximum dynamic metamorphism in the disturbed area is the zone of contact between the crystalline rocks and the sedimentaries. There is, moreover, an apparent transition from the sedimentary rocks on the outskirts of the mountain-range to the more or less foliated plutonic rocks occupying the central portions of the range. This transition was regarded by the earlier geologists as representing a transition in time—a transition from a supposed primordial condition of things, when granite and gneiss were deposited as sediments, to a condition when the globe was sufficiently cool to admit of the deposition of ordinary sediment and of the existence of organic life. This view is now rapidly disappearing in favour of the idea that the sequence above referred to is a structural and not a chronological sequence, except in so far as the oldest stratified rocks necessarily lie, as a general rule, nearest the mountain axis.

It must not, however, be supposed that wide-spread dynamic, or, in other words, regional metamorphism is limited to what are now great mountain ranges. It has operated in all regions of crystalline schist and also in many districts largely composed of rocks belonging to definitely recognizable geological periods—in short, wherever rocks have suffered great deformation by the earth-stresses.

In dealing with the effects of dynamic metamorphism we must, of course, remember that the plastic deformation of a mass of rock can only take place under immense pressure, and also that the mechanical energy expended upon the rock in the act of deformation will be transformed into other kinds of energy in the mass of the rock. It seems probable that the bulk of it will take the form of heat as in MALLET'S[1] experiments, and if so, a rise of temperature will be the result. It does not by any means follow, however, that the rise of temperature will be considerable. This will depend on the rate at which the heat is generated by deformation as compared with that at which it is dissipated by conduction. We are, therefore, at present totally unable to estimate the elevation of temperature which accompanies the deformation of rocks in any given case. It probably varies in different cases, and may sometimes be sufficient to melt (dissolve) the rocks in the presence of water, seeing that water tends to lower the fusing point of silicates. It seems tolerably clear from the occurrence of veins and segregations of quartz, quartz and albite, quartz and orthoclase (pegmatite), and other mineral aggregates in areas of regional metamorphism, that a migration and concentration of certain substances is rendered possible under the conditions which produce this kind of metamorphism.

For our present purpose it will be convenient to consider dynamic metamorphism under the following heads.

(1) As it affects the structure of igneous rocks.

(2) As it affects the composition of igneous rocks.

(3) As it affects the relations of rock-masses.

(1) Phil. Trans., Vol. 163 (1873) p. 147.

A massive igneous rock after it has been deformed by the earth-stresses possesses in general a more or less foliated structure which is easily recognizable in hand specimens. The darker and lighter constituents instead of being distributed uniformly through the mass are now arranged in wavy or parallel layers (see Plates XXVI. and XLIII.). The character of the parallel structure will depend upon the character of the deformation. If the ellipsoid of deformation be such that one axis is much longer than either of the other two then a kind of linear parallel structure will be developed; if, on the other hand, one axis be very much shorter than the other two a kind of plane parallel structure will be developed. If the original rock be porphyritic the resulting foliated rock will show "eye-structure." Such a structure, however, does not necessarily indicate that the original rock was porphyritic. If the deformation be comparatively slight, then, in the case of such rocks as coarse-grained granite and gabbro, the foliation will be of the flaser-type. If it be very great a more even foliation will result. Speaking broadly, we may say that the structure of typical schists is indicative of great deformation. The structures here referred to are due to the kind of deformation and not to the original composition of the rock. They are similar in rocks of such different composition as granite and gabbro (see Plate XLIII.). Thus we have granite, flaser-granite (gneiss), augen-granite (augen-gneiss), and mica-schist; gabbro flaser-gabbro, augen-gabbro and hornblende-schist.

Although a parallel structure is a very common feature in rocks that have been subjected to dynamic metamorphism it is not invariably present. Thus BRÖGGER[1] has shown that near Christiania the gneissose rocks pass into massive brecciated rocks in the neighbourhood of the great dislocation planes which correspond with the borders of the fjord.

A rock, which has been subjected to deformation subsequent to its consolidation, may consist wholly of original minerals, that is, of minerals formed before the deformation, and of the mechanical detritus of such minerals; or it may consist wholly of minerals formed during or subsequent to the deformation; or lastly, it may consist partly of original minerals and the detritus of such minerals and partly of secondary minerals. The micro-structure of the rock will be determined by the relations of the different constituents. In many cases there is, of course, a close relation between the macro- and micro-structures. The finer-grained rocks often show precisely the same structural characters under the microscope that the coarser-grained rocks do when viewed with the unaided eye.

The effects of mechanical force on the individual constituents are seen in the distortion and fracture of the minerals, and in the development of secondary structures, such as twin-lamellation and a kind of microcline-structure in the felspars. The fact that a mineral is in a state of strain

(1) Ueber die Bildungsgeschichte des Kristianiafjords. Nyt. Mag. Band XXX. Heft. 2, 1886.

reveals itself under the microscope in what is known as undulose extinction. When the limit of elasticity is exceeded the crystal is cracked or broken, and the separate parts may be more or less removed from each other. Very commonly the original minerals are more or less replaced by a micro-crystalline or crypto-crystalline aggregate of finer grain than the original rock. The partial replacement of the original minerals by such an aggregate is accompanied by the development of well-marked structural features. The relics of the original minerals are seen to lie in a secondary aggregate. Thus, in the case of a gneissose rock of granitic composition we frequently find that the centres of the light-coloured lenticles (see Fig. 1, Plate XLIII.) are occupied by a large irregular grain of felspar. This felspar passes at its margin into a granulitic aggregate. If the section be cut parallel to the greatest axis of the ellipsoid of deformation (direction of stretching) the ends of the lenticle will be seen to tail off into the more evenly-foliated rock, and these tail-like endings will consist of granulitic material. In general, we may say that, where large grains of the original constituents remain, the finer secondary aggregates sweep round them in the manner characteristic of what is called fluxion structure. It very commonly happens that definite planes of movement may be followed through a microscopic slide across the different constituents. When this is the case, these planes of strain are occupied either by the secondary granulitic or crypto-crystalline aggregate, or else by secondary minerals, such as mica (see Plate XLII.).

When all traces of the original form of the minerals have disappeared the entire rock shows a granulitic or crypto-crystalline structure. When mica has been extensively developed it takes the form of a mica-schist.

In the metamorphosed rocks which show a marked foliation, the orientation of the constituents stands in direct relation to the ellipsoid of deformation, their largest diameters lying parallel with the greatest axis of the ellipsoid. This renders it highly important that sections of foliated rocks should be cut in definite directions. The true character of a schist is best elucidated by preparing three sections; one parallel to the plane of schistosity; another perpendicular to this plane and parallel to the direction of stretching; and a third perpendicular to the schistosity and also to the direction of stretching.

A very common structure in deformed rocks in which a marked foliation has been developed is the occurrence of parallel veins and planes of inclusions which cut the foliation at a high angle. Veins of the kind here referred to are seen in Plate XXVI. In rocks containing quartz, parallel planes of liquid inclusions may often be seen traversing the slide and cutting the planes of foliation nearly at right angles. These are apparently connected with the extension which the rock has undergone in the direction of the greatest axis of the ellipsoid of deformation.

We have now to consider the effect of dynamic metamorphism on the chemical and mineralogical composition of the rock. In many cases the bulk-analysis of the metamorphosed rock is practically the same as that of the original rock. This, however, is not so in all cases. Nothing is more common than to find veins of quartz, quartz and albite, quartz and orthoclase (pegmatite), and other mineral aggregates in areas of great dynamic metamorphism. These veins evidently prove that a considerable migration of chemical constituents may take place, and if so an alteration in the composition of large masses of rock is a necessary consequence. BRÖGGER has shown that quartz veins increase in abundance as the faults which bound the Christiania Fjord in many places are approached, and that the gneissose rocks pass into a compact and highly siliceous rock resembling hornstone. Here we clearly see that "silicification" is connected with a somewhat special type of dynamic metamorphism.

Somewhat different from the question of chemical change is the question of mineralogical change. Old minerals are frequently destroyed, and new minerals are formed. Hornblende takes the place of pyroxene and olivine; epidote and zoisite are developed; basic felspars of the lime-soda group give rise to albite and other minerals. Of all the secondary minerals developed in connection with dynamic metamorphism, the micas, both black and white, are, perhaps, the most important. They are especially characteristic of those planes along which the movement has been greatest. The mica-schists represent the extreme of dynamic metamorphism, and they may be produced both from sedimentary and igneous rocks. The white micas are especially developed at the expense of the felspar; the dark micas at the expense of the ferro-magnesian minerals and of garnet.

It is very often difficult to distinguish between the original and secondary minerals. The latter are usually fresher, and do not, as a rule, give evidence of having suffered from mechanical action. They have the aspect of minerals which have been developed *in sitû*. In applying this test, however, great caution is requisite, because movements have occurred again and again in the same area. The last-formed minerals in metamorphic rocks (*e.g.*, pyrite in slate and halleflinta-like rocks; garnet in mica-schist) are often perfect in form. In this respect we note a marked difference between igneous and metamorphic rocks.

In conclusion we have to refer to the effect of dynamic metamorphism on the mutual relations of rock masses. Consider first of all the case of igneous dykes and sheets in sedimentary strata. Under normal conditions of intrusion the boundary is perfectly sharp. The igneous rock near the junction is, in general, finer in grain, but shows no schistosity. Sometimes fluxion structure is developed, but this, in general, may easily be distinguished from secondary schistosity. Such dykes and sheets in disturbed districts often possess very different characters. The central portion may be as massive as when the rock was first consolidated. The marginal portions often possess a secondary schistosity parallel with the cleavage in

the surrounding sedimentary rocks. If porphyritic crystals are present, as in the Ardennes' porphyroids, these may be more or less rounded and cracked at right angles to the direction of stretching, like the belemnites in the Jurassic rocks of the Alps. Secondary minerals, especially mica, have been developed on the planes of schistosity.

The schistose character becomes more and more marked as the junction is approached, and the actual junction is more or less obscured by a migration of constituents and the development of similar structures in both rocks. In short, the sequence, so far as structural features are concerned, as we pass outwards from the centre of the dyke or sheet into the surrounding sediments, is similar to that observed on a large scale in passing outwards from a central mountain-axis. The most perfect schists occur at the junctions of the two dissimilar kinds of rock, and the actual plane of junction becomes more or less obscure. In regions of intense dynamic metamorphism the original relations of the dyke or sheet to the surrounding rocks are often completely destroyed, and secondary schistosity, identical with that in the enveloping sedimentaries, pervades the entire mass of the igneous rock.

The case here referred to illustrates very well the general effect of regional metamorphism. This agency develops a secondary parallel structure in all rocks affected by it, whether igneous or aqueous, and causes a complex of rocks of different ages and characters to simulate a stratigraphical sequence. The strike and dip of the foliation-planes is determined, in the first instance, by the distribution of the stresses which produced the deformation, but is of course liable to be modified by later earth-movements. The theory of dynamic metamorphism, now rapidly gaining ground, is an extension of the views advocated long ago by Darwin,[1] Scrope,[2] and Sharpe.[3]

(1) Geological Observations on South America, p. 162—168, 1846. See also Geological Observations, 2nd Edition, 1876, p. 460—469.

(2) Geologist, No. IX., 1858, p. 361. See also Volcanoes, 1862, p. 298.

(3) Phil. Trans., 1852, p. 145.

THE END.

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GLOSSARY

OF

TERMS USED IN DESCRIBING ROCKS.

BY

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Accessory—A term applied to those mineral constituents whose presence or absence does not affect the character of a rock. Used in contradistinction to *essential*.

Acicular—In slender needle-like crystals, as mesotype.

Adélogène (*Fr.*)—A word used by Haüy for finely granular. It is synonymous with *aphanitic* and *cryptomerous*.

Æolian—A term applied to accumulations formed by the wind.

Aggregate polarization—The dappled appearance produced by a mineral aggregate under crossed nicols, due to the different orientation of the various particles.

Allochromatic—A term applied, in contradistinction to *idiochromatic*, to those minerals which owe their colour to the presence of a chemically dissolved, or mechanically included, pigment. Amethyst, fluor-spar, and rose-quartz are examples.

Allogenic (Allothigenic)—Applied to such minerals as are of more ancient origin than the rocks which they compose; as, for instance, the quartz-grains in a sandstone.

Allomorphism—*See* Paramorphism.

Allotriomorphic—A term applied by Rosenbusch (Mikroskop. Physiog. der massigen Gest., 1886, p. 11) in contradistinction to *idiomorphic*, to those mineral components of a rock which owe their form not to their own molecular arrangement, but to some other cause, *i.e.*, to such constituents as are not bounded by crystalline faces.

It is synonymous with *xenomorphic* (Rohrbach, T. M. M., VII., p. 18).

Amorphous—Structureless; non-crystalline.

A body is amorphous when it possesses the same elasticity in every direction.

Amygdaloidal (*Ger.* mandelförmig)—A term applied to eruptive rocks containing almond-shaped vesicular cavities (amygdules) which have become filled with infiltration-products (zeolites, calcite, quartz, chlorite, delessite, &c.).

Anisomerous—A name applied to the granular structure of a rock when the grains are of different sizes.

Anisotropic—Doubly refractive.

Anogenic—A term applied in geology, in contradistinction to *catogenic*, to rocks whose material has come up from below; it is thus synonymous with *eruptive*.

Anticlinal—A term applied to strata which dip away from a central axis. *See* Synclinal.

Aphanitic—A texture in which the component grains are so minute as to become visible only under the microscope. *See* Cryptomerous.

Apophysis (*Ger.* Gangausläufer)—A vein or branch from the main mass (boss or dyke) of an igneous rock.

Aqueous—Aqueous rocks are those which have been produced through the agency of water, either by the formation of chemical precipitates, or by the accumulation and deposition of rock-material suspended therein.

This term embraces, or is synonymous with, the following: *neptunic*, *hydatogenic*, *sedimentary*, *derivative*, *regenerated*, *indigenous*, *catogenic*, and *deuterogenic*.

Arenaceous—Composed of sandy material. *Syn.* Psammitic.

Argillaceous (*Fr.* argileuse; *Ger.* thonig; lehmig)—A term applied to rocks composed chiefly of clay. *Syn.* Pelitic or Pelolithic.

Assise (*Fr.* assise, couches; *Ger.* Schichten)—The name given to two or more beds or zones which contain a number of fossils in common, but separated from the next following, lower or higher, beds, by a marked palæontological difference, *e.g.*, the Micraster beds of the Cretaceous system. *See* Stratum.

Asymmetric—*See* Triclinic.

Atmogenic—A term applied to metamorphism produced by fumarole activity.

Ausweichungsclivage (*Ger.*)—A term applied by Heim (Mechanismus der Gebirgsbildung, Band II., p. 53) to Sorby's second type of cleavage (Q.J.G.S., Vol. XXXVI., Proc., p. 72). The cleavage-planes, in this case, are due to definite, inosculating planes of movement (shear-planes) which separate the rock into flat lenticles, inside which comparatively little deformation has taken place. The pre-existent planes of sedimentation or foliation are often recognizable in the lenticles. *Ausweichungsclivage* may be regarded as an advanced stage of minute puckering, some or all of the surfaces of contrary flexure having become shear-planes.

The expression "*strain-slip-cleavage*" has been used in this country with the same meaning.

Authigenic—A term applied by Kalkowsky (N.J., 1880, I., p. 4) to a mineral constituent, to denote that it came into existence with, or after, the rock containing it. In the one case it is primary; in the other, secondary. *See* Allogenic.

Automorphic—*See* Idiomorphic.

Avanturine lustre—Spangled lustre, like that of some oligoclase.

Axes of depolarization (*Fr.* lignes d'extinction)—Directions of extinction in any mineral section between crossed nicols. The two directions may be distinguished as the major and minor axes of depolarization.

Axes of Elasticity—*See* Elasticity (optic) of crystals.

Axiolite—A name given by Zirkel (Mic. Petrog. of 40th Paral., p. 173) to the elongated, sometimes branched, spherulitic bodies found in many rhyolites. They possess a fibrous structure, the fibres being normal to the long axis.

Axotomous—Cleavable in one direction.

Bacillar (*Ger.* stängelig)—Rod-shaped.

Bank—A word applied in stratigraphy to a bed which is thicker or more coherent than those in which it is intercalated.

Basal Plane—In the tetragonal and hexagonal systems the plane which cuts the vertical morphological axis at right angles, and runs parallel to the lateral axes. In the rhombic, monoclinic, and triclinic systems the term is applied to one of the three pinacoidal planes [*see* Pinacoid]. In each case it is parallel to the two lateral axes—*macro-* and *brachy-ortho-* and *clino*-diagonal respectively.

Base (*Ger.* Basis)—A term introduced by Zirkel (Mikrosk. Beschaffenh., 1873, p. 268) for the unindividualized ground-paste (*Grundteig*) of porphyritic rocks, and which may be, according to the nature of the substance composing it, either microfelsitic or glassy. It must not be confounded with "groundmass" (*q.v.*), which is used solely in a macroscopic sense.

Bauschanalyse (*Fr.* analyse en bloc)—The German expression for the bulk analysis of a rock.

Bed (*Fr.* couche; *Ger.* Lage)—The English committee of the International Commission for the Unification of Nomenclature suggested that the word *bed* be defined as that portion of a sedimentary deposit which is limited more or less distinctly by two successive divisional planes due to the mode of deposit. The word *layer* is applied to thin beds (*Fr.* lit), or to those portions into which a bed subdivides parallel to the stratification.

Belonite—A term used by Zirkel for a needle-shaped crystallite. Also applied by Allport to the hornblende microlites in the Arran pitchstone.

Belonospherite—A term proposed by Vogelsang (Die Krystalliten, 1875, p. 134) for spheroidal aggregates of crystalline material, showing radial structure; as, for instance, the concretionary bodies in the Napoleonite of Corsica, which consist of hornblende and anorthite. *Syn.* Needle-spherulite.

Biaxial—*See* Optic axis.

Bicuspid—With two prongs; forked.

Bifurcated (*Fr.* bifurqué; *Ger.* gezweigt, gegarbelt)—Terminally divided into two prongs, as, for instance, some microlites.

Bisectrices—The directions bisecting the angles formed by the optic axes. The two directions are distinguished as the acute and obtuse bisectrices; also called the first and second mean lines.

Blade (*Fr.* lâme; *Ger.* Blatt)—Used in petrography to designate a long narrow plate or lamella.

Bomb—The name given to masses of lava thrown out from a volcanic vent. These masses assume a spheroidal form in consequence of their having been ejected in a semi-molten condition.

Boss (*Fr.* amas, typhon; *Ger.* Stock)—The name given to an irregularly shaped mass of intrusive rock; also sometimes to masses of stratified rock which protrude through younger beds.

Botryoidal—In clusters, resembling bunches of grapes.

Brachydiagonal—The name sometimes given to the shorter of the two lateral axes in the rhombic and triclinic systems of crystals.

Brachypinacoid—One of the three principal crystallographic planes in the rhombic and triclinic systems. It runs parallel to the vertical axis and the shorter of the two lateral axes.

Brachypyramid; brachyprism; brachydome—*See* Pyramid, Prism, and Dome respectively.

Brecciated—Applied to a rock composed of angular fragments, in contradistinction to *conglomerate*.

Calcareous—Containing a large proportion of carbonate of lime.

Cancellated—Latticed; crossed by two series of parallel lines, as some triclinic felspars when twinned simultaneously on the albite and pericline types.

Carbonaceous—Containing some form of carbon, such as graphite or coal.

Cataclastic—A general term used by Kjerulf (Nyt. Mag. XXIX. 3, 269) to embrace all structures produced in rocks by a crushing of the constituent minerals. The separation of the broken mineral fragments can often be clearly made out under the microscope. *See* Clastic.

Catogenic—A term used in geology, in contradistinction to *anogenic*, to designate rocks which have been deposited. It is thus synonymous with *aqueous*.

Cellular—Containing irregular spheroidal or ellipsoidal cavities, as many lavas. The cellular structure is produced by the expansion of steam in the molten rock. *See* Vesicular, Pumiceous, Scoriaceous.

Centric structure—The name given to certain stellate arrangements of crystals, grains, or microlites around a central grain or aggregate of grains. This structure is common to both eruptive rocks and the banded crystalline series. *Syn.* Ocellar structure.

Chatoyant—Exhibiting a changeable lustre like that of the cat's-eye (*œil-de-chat*). Chatoyancy is allied to opalescence; according to Prof. Judd, it is caused by the presence of ultra-microscopic particles.

Cherty—Composed of, or resembling, chert.

Chloritic—Containing one of the chlorite minerals.

Clastic—Composed of fragmentary material, as the conglomerates, breccias, and sandstones. Mr. Teall ("Origin of Banded Gneisses," Geol. Mag., Nov., 1887, p. 493) suggests that this term should be applied to all rocks which consist largely of mineral fragments, and that we should distinguish between the three types of clastic rocks at present recognized, by using the terms epiclastic, cataclastic, and pyroclastic. *Epiclastic*—Rocks formed of fragments resulting from the breaking up of older rocks *upon* the earth's surface. *Cataclastic*—Rocks largely composed of fragments produced during the deformation of older rocks by the earth-stresses. *Pyroclastic*—Fragmental rocks of volcanic origin."

Clavate—Club-shaped.

Cleavage—(1) *As applied to minerals.* (*Ger.* Spaltbarkeit.) The property possessed by minerals of separating along certain planes. These cleavage-planes are parallel to the faces of one or more of the crystalline forms of the mineral.

(2) *As applied to rocks.* (*Ger.* Schieferung.) The fissile structure characterizing slates is also termed cleavage. These rocks split easily into thin laminæ along planes which do not necessarily coincide with, and bear no genetic relation to, those of bedding. Sorby and Tyndall have shown that cleavage can be produced artificially in a rock by pressure, the planes of cleavage being perpendicular to the direction thereof; and to this cause the phenomena of cleavage are now generally referred.

Cleavage-foliation—A term applied to that kind of foliation which is due to the development of secondary minerals along planes of cleavage.

Clinodiagonal—The name sometimes given to the inclined axis in the monoclinic system of crystals.

Clinopinacoid—One of the three principal crystallographic planes in the monoclinic system. It coincides with the plane of symmetry, and runs parallel to the vertical and to the inclined axis.

Clinopyramid; clinoprism; clinodome—*See* Pyramid, Prism, and Dome respectively.

Clinorhombic—*See* Monoclinic.

Compact—Applied to very fine-grained rocks in which the individual particles are too minute to be seen by the naked eye.

Conchoidal (*Ger.* muschelig)—Having the shape of a shell; applied to the concave and convex fracture of some rocks and minerals, as, for instance, obsidian and flint.

Concretionary—Applied to a rock-structure in which certain constituents have been so aggregated as to form nodules or irregular lumps.

Cone-in-cone structure (*Ger.* Tuten, Nägel)—A curious concretionary structure found in marls, limestones, and coals, and characterized by a concentric, conical arrangement of the rock material.

Conformity (*Ger.* concordante Auflagerung)—A term applied in stratigraphy to an uninterrupted sequence of beds having the same dip and strike.

Contact-metamorphism (*Fr.* métamorphisme de juxtaposition)—A term applied to the alteration of the surrounding rocks produced by the intrusion of igneous rocks (*exomorphic metamorphism*). Some geologists also include, under contact-metamorphism, the effect produced on the intrusive rock (*endomorphic metamorphism*).

Contemporaneous—Of the same age (*synchronous*); a term used in petrography to designate interbedded igneous rocks and segregation veins.

Corroded—A term often used in petrography to imply the destructive action of the molten magma of a rock upon the first-formed, or included, crystals.

Corrugated—Wrinkled, crumpled; applied to foliated rocks; also to shrinkage-surfaces.

Coulée (*Ger.* Strom)—The French word for a lava-flow or stream.

Crenitic—The name given by Sterry Hunt to his hypothesis of the origin of crystalline schists by the action of springs bringing up mineral matter in solution from below.

Cryptoclastic—An epithet applied by Naumann to clastic rocks whose fragments are of microscopic dimensions.

Cryptocrystalline—A term applied to rocks which are made up of minute crystalline particles. Under crossed nicols sections of such rocks show aggregate polarization, but the individual granules are too small for mineralogical determination.

Cryptogranitique (*Fr.*)—*See* Microgranitic.

Cryptomerous—A term used, synonymously with *adelogène*, for finely granular *See* Phaneromerous.

Crystalline (*Fr.* cristallin; *Ger.* krystallinisch)—This term is used by crystallographers to connote the physical properties of crystallized matter, and is applied to any body or portion of a body possessing those properties without regard to its form. By petrographers, on the other hand, the same word is used to denote mineral aggregates which consist of crystallized substances, whether in the form of perfect crystals or merely as grains possessing the physical properties of crystals. To remove this difficulty, J. Lehmann (Entstehung der altkryst. Schiefergest. 1884, p. 257) has suggested the introduction of the word *crystallic* (*Ger. krystallisch*), to replace crystalline in the former of the two meanings given above. *See* Holocrystalline, Hypocrystalline, &c.

Crystallite—This term, first proposed by Sir James Hall, has been adopted by modern petrographers with slightly varying meanings. By some it is used as a general designation for all the indefinitely crystalline or incipient forms of individualization of minerals, and is thus made to include such forms as microlites; while by others it is restricted to such products of incipient crystallization as are not sufficiently individualized to exert any definite action on polarized light. It would thus embrace the terms globulite, longulite, margarite, trichite, but not microlite, which is applied to those forms which can be recognized by their optic behaviour as belonging to a definite mineral species. Thus we speak of microlites of felspar, augite, &c. *Syn.* Mikromorphit (Gümbel).

Crystallogenesis—The development or growth of crystals.

Crystalloid—A term applied by Vogelsang (Die Krystalliten, Bonn, 1875, p. 43) to microscopic bodies which are intermediate in development between crystallites and microlites; *i.e.*, they are bodies which, without possessing crystallographic contours, react on polarized light.

Cube (*Ger.* Würfel)—One of the simplest forms belonging to the regular system of crystals. It is contained by six equal squares, each of which cuts one axis at right angles, and runs parallel to the other two, thus coinciding with the three chief planes of symmetry of this system.
Syn. Hexahedron.

Cubic—*See* Regular system.

Cuboidal (*Ger.* quaderförmig)—Applied to the rudely rectangular masses into which certain igneous rocks, especially granite, weather. Their form is determined by an intersecting system of horizontal and vertical joint-planes.

Cumulite—A term applied to cumulous accumulations of globulites in vitreous rocks.

Cuneiform, or Cuneate—Wedge-shaped; as, for example, sphene.

Cup-and-ball structure—A cross-jointing of columnar igneous rocks, accompanied by a depression on one side of the joint-plane and a corresponding elevation on the other, the two parts fitting into one another. Basalt furnishes a familiar example.

Cuspidate—Spear-shaped; tapering abruptly. Twin-crystals of rutile often give cuspidate sections.

Damascened—A term suggested by Rutley (Study of Rocks, 1879, p. 181) "to describe the structure shown in some obsidians, in which streaks or threads of glass are contorted in a confused manner, which somewhat resembles the workings on Damascus sword-blades or the damascening on gun-barrels."

Dendritic—A term applied to certain arborescent growths of mineral matter, occurring often on the surfaces of joints and fissures in rocks, or pervading certain limestones, as, for instance, the Cotham or landscape-marble.

Derivative—*See* Aqueous.

Detrital—A term applied to rock-material resulting from the disintegration of pre-existing rocks.

Deuterogenic—*See* Aqueous.

Deuteropyramid; deuteroprism—*See* Pyramid and Prism.

Devitrification (*Ger.* Entglasung)—The process by which glass assumes a lithoid character. According as the devitrification of the glassy base of rocks takes place during, or subsequent to, their consolidation, it may be termed *original* or *secondary*. *Syn.* Promorphisme (Lévy).

Diaclase—*See* Joint.

Dialytic—A term applied by Naumann to such rocks as are derived from the chemical decomposition of pre-existing rocks; as, for example, kaolin, clay, &c. *Syn.* Cimmatic.

Dichroism—*See* Pleochroism.

Dimorphism—*See* Polymorphism.

Dip (*Fr.* inclinaison; *Ger.* Einfall)—A term used to express the relation between the plane of a bed or stratum and the plane of the horizon. It is measured by the angle which the plane of the bed makes with the plane of the horizon.

Dislocationsmetamorphismus (*Ger.*)—*See* Mechanical metamorphism.

Disomatic—A term applied by Seiffert and Söchting to a crystal and its inclusions when each belongs to a different mineral species. *See* Monosomatic.

Dome—A term used in crystallography for forms which may be considered as lateral prisms, *i.e.*, they run parallel to a lateral instead of to the vertical axis. Like the prisms, too, they may be treated as special cases of the pyramids, namely, those in which the pyramidal faces cut one of the lateral axes at an infinite distance. Corresponding to each class of pyramid, in rhombic, monoclinic, and triclinic systems respectively, we have consequently *macro-*, *brachy-*, *ortho-*, and *clino*-domes. *See* Pyramid.

Dôme (*Fr.*)—The name given to certain hills of rounded form (*Ger.* Kuppe), generally of volcanic origin, and owing their shape, when composed of igneous material, to the viscid nature of the lava at the moment of eruption.

Double-spheric structure (*Ger.* Doppelt-sphärische Structur)—The name given to a rock structure in which a number of small spherulites are arranged in concentric layers around real or imaginary nuclei to form spheroidal aggregates.

Druse—A term used in descriptive petrology for cavities in rocks which are sprinkled over with crystals, or into which freely terminated crystals project.

Dyke (*Ger.* Gang)—A term applied to intrusive rocks which occur in *wall*-like masses, cutting through the adjacent rocks.

Dynamic Metamorphism—*See* Mechanical Metamorphism.

Effusive—A term lately used abroad for those rocks which have been poured out at the surface, the word *eruptive* now being generally used for the whole group of massive rocks.

Einsprengling (*Ger.*)—A word used by German authors to designate the larger mineral constituents disseminated in the groundmass of a rock. The only English equivalent is "Porphyritic constituent."

Elasticity (optic) of crystals—In uniaxial crystals the elasticity is different in different directions, but is the same for all directions which make the same angle with the optic axis. The greatest difference of elasticity exists between the direction of the optic axis and a plane perpendicular to this. When the optic axis coincides with the direction of greatest elasticity the crystal is optic *negative*; when of least, optic *positive*. In the former case the extraordinary is less refracted than the ordinary ray (the crystal is *repulsive*—calcite); in the latter the extraordinary is more refracted than the ordinary ray (the crystal is *attractive*—quartz). In biaxial crystals, on the

other hand, there exists no direction around which the elasticity varies similarly in all directions. There are, however, three directions, standing at right angles to one another, which correspond to the greatest, least, and mean elasticity. These are termed *axes of elasticity*. In Germany they are distinguished by the German (or Old English) letters:—a=axis of greatest elasticity; b=axis of mean elasticity; c=axis of least elasticity. In France and England the Greek letters α, β, γ are used in the same order; whereas in Germany these are used to express the indices of refraction, α being the least, β the mean, and γ the greatest index of refraction. A biaxial crystal is negative when the axis of greatest elasticity coincides with the acute bisectrix of the angle between the optic axes; it is positive when the axis of least elasticity occupies that position.

Enantiomorphic—The name given to such hemihedral and tetartohedral crystals as have no plane of symmetry. Of these there are always two, a right and a left-handed, which have the same relation to one another as an object to its image or a right glove to its fellow.

Endogenous—*See* Endomorphic.

Endomorphic—Applied, first by Fournet, to contact-metamorphism when produced in the erupted rock. It is used in contradistinction to *exomorphic*. *Syn.* Endogenous.

Entoolitic—A term applied by Gümbel (N. J., 1873, p. 303) to oolitic grains which have grown from outwards, and are therefore often hollow in the interior. Oolitic grains of this kind are produced in the hot springs of Carlsbad. Their growth is often started by carbonate of lime being deposited round floating bubbles. The thin film thus formed, increasing in thickness as the dancing bubble moves rapidly about, ultimately becomes sufficiently heavy to carry the spherule to the bottom.

Epigenetic (*Fr.* épigénisé)—An expression applied to the formation of secondary minerals by alteration processes.

Erratic—The name given to a block of any rock which has been detached from the parent mass and transported to its present site by any agency, but more especially by ice.

Eruptive—A term now used generally to designate all igneous rocks, whether interstratified or not. By some writers, however, it is restricted to rocks poured out at the surface. *See* Effusive.

Essential—The essential constituents of a rock are those which determine its character, and which must therefore be present in its typical development.

Estuarine—A term applied to rocks deposited in the mouth of a river.

Euritic—A term used by some petrographers in the sense of *cryptogranitic*, *i.e.*, a granitic structure in which the individual grains are of microscopic dimensions. N.B. The eurites are microgranites.

Eutaxitic—A name applied to lavas in which the texture changes rapidly in a direction normal to the direction of flow. Eutaxitic lavas are thus often composed of layers, each of which has its characteristic structure. The term is sometimes also extended to banded igneous rocks which have not flowed at the surface.

Exfoliation—A separation into laminæ or scales, an effect often produced by weathering on rocks.

Exogenous—*See* Exomorphic.

Exomorphic—Applied by Fournet to contact-metamorphism when produced in the rock through which the molten mass is erupted. Used in contradistinction to *endomorphic*. *Syn.* Exogenous.

Exoolitic—A term applied by Gümbel (N. J., 1873, p. 303) to oolitic grains which have been formed by deposition around a nucleus of any kind. It is used in contradistinction to *entoolitic*.

Exotic—*See* Igneous.

Extinction (*Ger.* Auslöschung)—A mineral section becomes dark (extinguishes) under crossed nicols when the axes of the ellipse in which it cuts the ellipsoid of elasticity (axes of depolarization) coincide with the chief planes of the nicols.

Extinction-angle (Auslöschungsschiefe)—The angle between a position of extinction (axis of depolarization) and the trace of some definite crystallographic plane.

Eye-structure (*Ger.* Augenstructur)—In this structure, which is characteristic of the metamorphic rocks, more particularly of the coarsely crystalline ones, the foliated and secondary minerals are arranged in layers round the larger original constituents, producing lenticular forms which often bear a striking resemblance to eyes.

Face—The bounding plane surfaces of crystals are termed faces.

Fascicular (*Ger.* buschelförmig)—Aggregated in tufts or bundles of needles. *Syn.* Tufted.

Fault (*Fr.* faille; *Ger.* Verwerfung, Wechsel, Sprung, Verschiebung)—A displacement of rocks along planes usually inclined at a high angle (the *hade*) to the horizontal surface. In a *normal* fault the downward displacement is in the direction of the hade. Faults in which this is not the case are termed *reversed* faults. *Syn.* Throw, Heave, Slip, Trouble, Dyke, Paraclase.

Felsitic (*Fr.* petrosiliceuse)—The name applied to the macroscopically homogeneous groundmass of many porphyries, and by most English petrographers to the rocks themselves. Under crossed nicols, *felsitic* (not *microfelsitic*) matter gives a micro- or crypto-crystalline reaction.

Felsophyric—A term applied to certain quartz-porphyries of which the groundmass consists mainly of microfelsite, but may also contain cryptocrystalline aggregates.

Felsospherite (*Fr.* sphérolites petrosiliceux à croix noire)—*See* Spherulite.

Felspar-mosaic—The name given to felspar when occurring in aggregates of clear, variously orientated granules, packed together like the pieces composing a Roman mosaic. It is especially characteristic of rocks which have undergone mechanical metamorphism.

Felspathic—Containing a large proportion of felspar; generally applied to the groundmass of a rock.

Felted (*Ger.* filzig; filzartig)—Applied to any aggregate of microlites (*mikrolithenfilz*) forming a compact mass like the hairs in felt.

Fibrous—Composed of fibres or threads, as in asbestos, amianthus.

Fissile—Admitting of being split into laminæ.

Fluid-cavity—*See* Inclusions.

Fluxion- or **fluidal structure** (*Fr.* texture fluidale; texture d'écoulement)—A structure characteristic of eruptive rocks, and especially of the more vitreous types. It assumes one or more of the following forms: (1) a parallelism of differently coloured glass bands (*Schlieren*); (2) an arrangement of crystallites and microlites with their long axes parallel; (3) an arrangement of different crystallites in parallel layers; (4) the smaller and later constituents sweeping round the larger and first-formed crystals. All

these forms of fluxion-structure owe their origin to differential movements in the molten magma.

Foliaceous—A lamellar structure in which the laminæ are thin and easily separable.

Foliated—Composed of thin layers or folia. Applied to the crystalline schists, in which the minerals are arranged in parallel, sometimes wavy, layers. *See* Schistosity.

Formation—This word has been applied to a group of rocks, less than a system, having in common certain petrological or paleontological characters, but not necessarily separated by a break from the next following series above or below it. In this sense it is synonymous with the word proposed for this statigraphical subdivision at the Bologna meeting of the International Geological Congress, viz., *series*, or *section* (*Fr.* séries ; *Ger.* Abtheilung). The word formation has also been used to express the idea of origin, and not of time ; thus, it would be correct to speak of an eruptive formation, a sedimentary formation, marine, lacustrine, or detrital formations, but not of a Cretaceous, Jurassic, or Carboniferous formation.

Fracture (*Fr.* cassure ; *Ger.* Bruch)—The freshly broken surface of a mineral or rock. It may be smooth, rough, splintery, hackly, conchoidal, &c.

Friable—Easily crumbled ; reducible to powder.

Fusiform—Spindle-shaped, as the banding seen in microcline under crossed nicols.

Gang—The German term for a dyke, vein, or lode of a rock or mineral.

Gas-cavity—*See* Inclusion.

Geode—Originally applied to nodules of indurated clay or ironstone. Now used to denote any hollow nodular body, whether empty or lined with crystals.

Glass-cavity—*See* Inclusion.

Glassy Base (*Fr.* pâte vitreuse ; *Ger.* Glasbasis)—This term is employed to denote the residual uncrystallized, and therefore structureless and isotropic, portions of a rock.

Gliding-plane (*Ger.* Gleitfläche)—A definite direction in a crystal in which the molecules glide over one another when it is subjected to a suitably directed pressure.

Globospherite—A term used by Vogelsang (Die Krystalliten, p. 134) to designate those spherulites which consist of globulites in radial arrangement.

Globulite—The name given by Vogelsang (Die Krystalliten, p. 134) to minute crystallites having a spherical drop-like form. *See* Crystallite.

Glomero-porphyritic—The name given by Judd (Q.J.G.S., 1886, p. 71) to a porphyritic rock-structure in which the porphyritic constituents are granular aggregates.

Granitic (*Fr.* structure granitique, Lévy)—A term applied to holocrystalline rocks having the allotriomorphic-granular structure of the granites.

Granitoid—Resembling granite in structure.

Granito-trachytic—*See* Ophitic.

Granophyric—A structure characteristic of certain quartz-porphyries (granophyres) and of some granitic rocks, in which the quartz and felspar of the ground-mass, having consolidated simultaneously, occur in micropegmatitic intergrowth, often forming radially fibrous spheroidal bodies (pseudo-spherulites).

Granospherite—A term applied by Vogelsang (Die Krystalliten, p. 135) to spherulites which consist of an irregular aggregate of crystalline grains, showing aggregate polarization under crossed nicols.

Granular (*Fr.* grenu; *Ger.* körnig)—Composed of rounded grains or irregular crystalline particles, as sandstone, marble, and granite.

Granulation—As used in petrography a term signifying a breaking-up into granules of the mineral constituents (usually the quartz or felspar) of a rock, a phenomenon often accompanying dynamic metamorphism. *See* Cataclastic Structure.

Granulitic—Michel-Lévy (B.S.G., 3e sèrie, II., p. 177; III., p. 204) applies this term to holocrystalline rocks composed of juxtaposed grains, all approximately of the same size and independently orientated. Under crossed nicols such a rock has the appearance of a brilliantly coloured mosaic. When the grains are of microscopic dimensions the structure is said to be micro-granulitic.

Groundmass—The groundmass of a rock is the matrix in which the porphyritic crystals are embedded. It may be holocrystalline, hypocrystalline, or consist entirely of a glassy or microfelsitic base.

Hackly—Rough; having fine, short and sharp points on the surface; as a hackly fracture, *e.g.*, the fracture of the native metals.

Hardness (*Fr.* dureté; *Ger.* Härte)—By hardness is understood the resistance offered by a body to the separation of its particles. This resistance is termed *coherence*. The hardness of a mineral is measured by the force required to scratch it with a steel point or other sharp-pointed fragment of some harder mineral. The results obtained from one and the same mineral are found to vary slightly with the crystalline face experimented on, and even with the direction in one and the same face. Relative hardness may be expressed by reference to the following scale (Mohs):—

1. Tale.
2. Selenite.
3. Calcite.
4. Fluor-spar.
5. Apatite.
6. Orthoclase.
7. Quartz.
8. Topaz.
9. Sapphire.
10. Diamond.

Hemiclastic (*Ger.* halbclastisch)—A term applied to a rock composed of detrital constituents united by a secondary cement; as, for instance, many quartzites.

Hemicrystalline—A term applied by Prof. Bonney to rocks possessing a structure intermediate between holocrystalline and hyaline. This intermediate division contains "the rocks often called cryptocrystalline with some of the microcrystalline." The material of such rocks "appears to have lost the usual property of a colloid, to have acquired, around innumerable centres, polarities in one or more directions, without its being possible to distinguish with precision what are the minerals into which it has segregated." (Bonney, Address to the Geol. Soc., 1885, p. 38.)

Hemihedral—The term applied to crystals which present only half the full number of faces, the others having disappeared in accordance with some law of symmetry.

Hemimorphism—The property possessed by some crystals (not belonging to the regular system) of presenting the faces of totally different forms at the opposite ends of an axis of symmetry. Such crystals show electrical polarity.

Hémitrope—The French expression for twinned (*q.v.*). The etymology of the word has reference to the revolution of 180°, round an axis normal to the twinning-plane, which the one portion of a crystal is assumed to make in order to bring it into the twinning position.

Hexagonal—The name given to one of the six systems of crystals. It is characterized by seven planes of symmetry. The forms of the hexagonal system are referred to four axes, three of which are equal and similar, and cross one another at an angle of 60°; while the fourth (the chief axis) is unequal and dissimilar, and stands at right angles to the plane of the other three.

Syn. Rhombohedral, Monotrimetric, Drei-und-einaxiges.

Hexakisoctahedron (*Ger.* Acht-und-vierzigflächner)—The most general of the forms belonging to the regular system. It is contained by 48 scalene triangles; and each face cuts one axis at unit distance, one at a distance measured by a rational quantity m, and the third at a distance measured by a rational quantity n. By the variation of the values for m and n, the hexakisoctahedron may be made to approximate successively to all the simpler forms of the regular system (octahedron, cube, rhombic, dodecahedron, &c.).

Hollow Spherulites (*Ger.* gekammerte Spheruliten)—A generic name for such spheroidal bodies, occurring in rocks, as have a cavernous interior.

Syns. Chambered spherulites, Lithophysæ (*q.v.*).

Holocrystalline (*Ger.* vollkrystallinisch)—Composed wholly of crystalline material; having no interstitial, glassy, or microfelsitic matter.

Holohedral—The term applied, in contradistinction to *hemihedral*, to crystals which present the full number of faces required by the symmetry of their system.

Homœocrystalline—A term applied by some authors to a granitic structure when the minerals are developed in equal proportions.

Homomikt (*Ger.*)—*See* Monogenous.

Hour glass structure (*Ger.* Sanduhrglassstructur)—A remarkable case of zonal growth presented by the augites (less often by the hornblendes) of some basic rocks. Viewed under crossed nicols, a section of the crystal, cut parallel to the clinopinacoid, appears divided into four parts, of which those lying opposite to one another show similar optic orientation, thus producing a striking resemblance to the shape of an hourglass. A section parallel to the orthopinacoid behaves in a like manner; while sections perpendicular to the vertical axis show only the usual zonal growth. This structure appears to be produced by the formation of a skeleton crystal shaped like an hour-glass, the central depression of which is afterwards filled in by augitic material of a slightly different chemical composition, and extinguishing therefore at a different angle.

Hyaline—Of the nature of glass.

Hyalopilitic—*See* Pilotaxitic.

Hydatogenic—*See* Aqueous.

Hydrothermal—A term applied to phenomena which are caused by the combined action of heat and water (steam).

Hypidiomorphic (Rosenbusch, Die massigen Gesteine, p. 11)—Composed in part, only, of idiomorphic crystals. *See* Idiomorphic.

Hypocrystalline—Composed partly of crystalline, partly of amorphous, matter (glassy or micro-felsitic base).

Hypometamorphic—A term used by Callaway for the transitional forms between the slates and shales on the one hand, and the schists on the other.

Icositetrahedron—The icositetrahedra are a series of forms contained by twenty-four deltoids (a plane quadrilateral figure bounded by pairs of adjacent equal straight lines), the limits of which are formed by the octahedron and cube respectively. Each icositetrahedral face cuts one axis at unit distance, the other two at a distance measured by a rational quantity *m*.

Idiochromatic—A term applied, in contradistinction to *allochromatic*, to those minerals which possess an essential, and therefore characteristic colour, *e.g.*, the metals and many of their salts.

Idiomorphic—A term introduced by Rosenbusch ("Die massigen Gesteine, p. 11). The mineral constituents of rocks are said to be idiomorphic in so far as they are bounded by faces peculiar to the species. The word is synonymous with Rohrbach's "*automorphic*" (T.M.M., VII., p. 18).

Igneous—A term employed in petrology to include rocks which have been formed by the consolidation of molten material. The words *pyrogenic*, *ingenitic*, or *exotic* are preferred by some authors.

Imbricated—(*Fr.* imbriqué; *Ger.* dachziegelartig)—Overlapping like the slates of a roof. Tridymite occurs in rocks in imbricated plates.

Inclusions—This term is used in petrography, first with regard to minerals, secondly with regard to rocks. (1) Most of the minerals composing a rock contain inclusions (interpositions) either of gas, liquid, glass (fresh or devitrified), and crystals or microlites of other minerals (*See* Figs. 8, 9, 10, and 11 of text). (2) As applied to rocks, the term refers to pieces of other rocks which have been caught up by the molten magma and remain embedded in the rock when it consolidates. They must be distinguished from certain concretionary patches in granite and other rocks, which they much resemble.

Indigenous—*See* Aqueous.

Ingenitic—*See* Igneous.

In situ—(*Ger.* anstehend)—In place.

Interbedded—Bedded between; (1) as applied to igneous rocks, the word is synonymous with *contemporaneous*, and implies that the rock must have flowed at the surface; (2) as applied to sedimentary rocks, it merely expresses an alternation of beds.

Intercept—The distance from the origin (or point of intersection of the axes) at which a face cuts a crystallographic axis.

Interference-figure (*Ger.* Axenbild)—The figure which is obtained when a section of a doubly refractive crystal is examined in convergent polarized light.

Interlaced structure (*Fr.* structure entrelacée; *Ger.* durchflochtene Structur)—A structure occurring in schistose rocks, in which lamellated or granulated mineral-layers meet and intersect so as to produce a kind of network, in the meshes of which lie the lenticular portions (*eyes*) of the rock.

Intersertalstructur (*Ger.*)—The name given by Rosenbusch (Mikros. Physiog. der massig. Gest., p. 504) to a rock-structure found especially in a certain class of porphyrites (Tholeiites). It is characterised by the presence of an interstitial substance (*mesostasis*) which is hypocrystalline, but not rich in micro-felsitic or glassy base. This substance occurs in irregular masses wedged in between the lath-shaped felspathic constituent.

ntratelluric—A term applied by Rosenbusch (Physiog. der massig. Gest., p. 8) to that period in the formation of a rock which immediately precedes eruption (effusion); also to the minerals which separate out during that period.

Intrusive (*Ger.* durchgreifende Lagerung) — Applied to those igneous rocks which have been injected or intruded into other rocks. In this meaning it embraces perhaps all igneous rocks which have not flowed at the surface.

Irruptive—A term used by some authors in contradistinction to *eruptive* for those intrusive rocks which do not reach the surface.

Isomerous—An epithet applied to the granular structure of a rock when the grains are equal size.

Isometric—*See* Regular.

Isotropic—Applied to substances which are not doubly refractive, and consequently always remain dark under crossed nicols.

Joint (*Ger.* Absonderung, Fuge, Zerklüftung)—The name given to the divisional planes, other than those of bedding or schistosity, which separate rocks into more or less regular blocks. Daubrée ("Les eaux souterraines à l'époque actuelle," Paris, 1887) uses the word *lithoclase* to embrace all kinds of rock-fractures. These he further subdivides as follows: *diaclases* (joints), *paraclases* (faults), *synclases* (joints due to contraction), *leptoclases* (minute fissures).

Kaolinized—A term applied to altered felspar when the decomposition has resulted in the formation of kaolin—a hydrated silicate of alumina. This mineral occurs, under the microscope, in cumulous aggregates of minute scales and granules, producing turbidity, or even opacity in the felspar.

Kelyphit-structur (*Ger.*)—A variety of *centric structure* (*q.v.*) in which crystals of garnet are surrounded by a *shell* of radiating needles of augite or hornblende.

Knotted—A term applied in petrology to certain nodular schists (Knotenschiefer) which contain little concretionary knots. These are sometimes imperfectly developed (incipient) crystals of chiastolite, andalusite, &c., sometimes pseudomorphs after cordierite or andalusite.

Kramenzel-structur (*Ger.*)—The name given to a variety of *interlaced structure* (*q.v.*) developed in certain sedimentary rocks—typically in those of the Devonian age. In the meshes of a network of slaty material are enclosed small flat nodular masses of limestone (Kramenzel-schiefer).

Krithic Structure—This term has been applied by Becke (T. M. M., II., p. 43) to a structure characterizing certain mica schists in which grains of orthoclase occur wrapped round by thin layers of quartz and mica. It is probably a phenomenon of dynamic metamorphism.

Laccolite—A term proposed by G. R. Gilbert (Geology of the Henry Mts., 1880) for large masses of rock which, while molten, have risen from below, and not being able to find their way to the surface, have spread out laterally and elevated the superincumbent strata, so as to produce bosses having the form of plano-convex lenses.

Lacustrine—A term applied to sedimentary rocks which have been deposited in lakes.

Lamella—A term used in microscopic petrography for a thin plate. Hence *lamellar*, *lamellated*, as, for example, the lamellar twinning in plagioclase felspar.

Lamina—A thin leaf-like plate. Hence *laminar*, *laminated*, as, for example, the lamination of shales.

Lanceolate—Lance-shaped; tapering gradually.

Lapilli—A general term applied to the irregular small fragments of eruptive rocks (and, by some authors, also to the broken crystals) which occur in volcanic ashes.

Lattice structure (*Ger.* Gitter-, or Fenster-structur)—In serpentines, derived from hornblende-bearing rocks, the alteration has proceeded along cleavage-cracks which intersect one another at an angle of about 124°, thus producing a lattice-work with lozenge-shaped interstices. This structure was first described by Weigand (T.M.M., 1875, p. 183). *See* Mesh and Netted structure.

Lava—Lava, in its general sense, denotes all rocks which have flowed at the surface while in the molten state.

Lenticular (*Ger.* linsenförmig)—Shaped like a lens.

Leptomorph (*Ger.*)—A word used by Gümbel to designate a body which, though crystallized, is not bounded by crystallographic faces. It was first applied by him to the so-called "nepheline-glass" of some of the nepheline basalts. *See* Allotriomorphic.

Libella (*Fr.* bulle; *Ger.* Bläschen)—The bubble of air or gas contained in liquid and glass inclusions, and which may be vibratile or fixed.

Linear-parallel structur (*Ger.*)—That structure in rocks in which the mineral components are elongated in one direction (*Ger.* Streckung). This may be due (1) to differential movement in the magma while still molten (fluxion); (2) to mechanical deformation of the consolidated rock.

Lithoclase—*See* Joint.

Lithogeny—That department of petrology which treats of the formation of rocks.

Lithoid—Stony, a term often used in the description of devitrified glass.

Lithology—The study of rocks; used by some authors to designate more especially the study of rocks when confined to the laboratory. *See* Petrography.

Lithophysae (*Ger.* gekammerte Späroliten)—The name given by Richthofen (J.G.R., 1860, p. 180) to a concentrically chambered variety of hollow spherulites. Iddings has lately proposed that the term should be extended to all forms of hollow spherulites.

Littoral—A term applied to sedimentary rocks, which are formed on the sea-shore.

Longulite—A term proposed by Vogelsang (Die Krystalliten, p. 21) for crystallites of an elongated cylindrical, elliptical, or conical shape.

Lustre (*Ger.* Glanz)—A term used in describing the character of the reflections obtained from the fractured surfaces of minerals and rocks. There are several kinds of lustre: *metallic*, *adamantine*, *greasy*, *vitreous*, *resinous*, *pearly*, *silky*, &c.

Lustre-mottling—A term proposed by Pumpelly (Proc. Amer. Acad., Vol. XIII., p. 260) for the intermittent lustre obtained from the large cleavage-faces of a mineral containing numerous inclusions. The ophitic masses of augite in some dolerites present this phenomenon. Synonymous with G. R. William's "poicilitic."

Mâcle—Twin (*q.v.*).

Macroclastic—A word used by Naumann for such clastic rocks as are made up of large-sized fragments.

Macrodiagonal—The name sometimes given to the longer of the two lateral axes in the rhombic and triclinic systems of crystals.

Macropinacoid—One of the three chief crystallographic planes in the rhombic and triclinic systems. It is parallel to the vertical axis and the longer of the two lateral axes.

Macropyramid; Macroprism; Macrodome—*See* Pyramid, Prism, and Dome respectively.

Macroscopic—A term used in contradistinction to *microscopic*, to imply that the character in question is visible to the naked eye. *Syn.* Megascopic.

Maculated—Spotted; applied to rocks which have a spotted appearance.

Magma (*Fr.* pâte; *Ger* Teig)—The molten mass or paste which by consolidation gives rise to a rock.

Margarite—The name given by Vogelsang (Die Krystalliten, p. 19) to the linear arrangement, like strings of beads, assumed by globulites (*q.v.*).

Marmorosis (*Ger.* Marmorisirung)—The word proposed by Dr. A. Geikie (Text-book of Geology, 1882, p. 577) to express the metamorphosis of ordinary limestones into crystalline marble.

Massive (*Fr.* massif; *Ger.* massig, richtungslos, ungeschichtet)—Unstratified; occurring in homogeneous masses. By some authors this word is used synonymously with *eruptive*.

Matrix (*Fr.* moule)—The groundmass of an igneous rock; also the calcareous or siliceous paste in which the pebbles of a conglomerate are embedded. *See* Base and Mesostasis.

Mechanical metamorphism—The metamorphism produced in a rock by mechanical processes—earth movements, shearing, &c., involving—always a structural and generally a mineralogical change.

Syns. Dynamic metamorphism, Pressure-metamorphism, Dislocationsmetamorphismus (*Ger.*).

Megascopic—*See* Macroscopic.

Merohedrism—A crystallographic term embracing both *hemihedrism* and *tetartohedrism* (*q.v.*).

Mesh structure (*Ger.* Maschenstructur)—The reticulated structure peculiar to the serpentines derived chiefly from the alteration of olivine.

Mesostasis (*Ger.* Zwischenklemmungsmasse)—The interstitial matter (glassy, microfelsitic, or cryptocrystalline) of hypocrystalline rocks.

Metacrasis—A word suggested by Prof. Bonney (Proc. Geol. Soc., 1886, p. 59) to denote "changes like the conversion of a mud into a mass of quartz with mica and other silicates."

Metamorphism—This word is usually restricted in geological literature to changes which a rock undergoes in mineralogical or chemical composition and internal structure through the operation of heat, heated water, or vapour, and mechanical agencies. It is either local or regional.

Metapepsis—A term suggested by Kinahan (in his Geology of Ireland, 1878), for metamorphism which "seems to be due to intensely heated water or steam, which, as it were, stews the rock."

Metasomatosis—The change of material, due to chemical agencies, undergone by rocks subsequent to their formation. *See* Paramorphosis.

Metastasis—A word suggested by Professor Bonney (Proc. Geol. Soc., 1886, p. 59) to denote "changes rather of a paramorphic character, such, for example, as the crystallization of a limestone, the devitrification of a glassy rock."

Miarolitic—A term applied by Rosenbusch (Die massigen Gesteine, p. 39) to granitic rocks which are characterized by the presence of small irregular cavities, into which the corners and edges of the crystallized mineral components project.

Micaceous—Containing a notable proportion of mica.

Microclastic—An epithet applied by Naumann to such clastic rocks as are composed of small fragments.

Microcline structure—The mineral microcline shows in certain sections, under the microscope, a cross-hatching (*Ger.* Gitterstruktur) which is remarkable for its irregular and ill-defined appearance. It is generally referred to lamellar twinning simultaneously on the albite and pericline types. It is distinguished, however, from ordinary cross-twinning by the fact that the lamellæ are spindle-shaped.

Microfelsite—A term first introduced by Zirkel, and since used in a slightly varying sense by different authors. (*See* Rosenbusch, Die massigen Gesteine, p. 370.) It is now generally defined as a microscopic substance, forming the base of some porphyries, which is characterized by the possession of a granular, scaly, and fibrous structure without the power of exerting any definite action on polarized light. Rosenbusch states, however, that when aggregated in parallel or radial masses, microfelsite shows weak double refraction.

Microfluxion-structure—*See* Fluxion structure.

Microgranitic—A term applied to a rock, or portion of a rock, which is holocrystalline, and is composed of minute allotriomorphic granules.

Microgranulitic (structure microgranulitique of Lévy)—*See* Granulitic.

Microlite—By most authors this term, first proposed by Vogelsang (Philos. d. Geol., 1867, p. 139), is now generally restricted to those minute crystalline bodies, mostly lath-shaped, but sometimes bifid or with ragged terminations, which can be identified as belonging to some definite mineral species. Rosenbusch, in his later editions, does not distinguish between microlites and crystallites. *See* Fig. 5 of text.

Micropegmatite—As generally used, this term is applied to the microscopic representative of graphic granite (*pegmatite*, Haüy); *i.e.*, to an intimate intergrowth of quartz and felspar in which each mineral exhibits, independently of the other, uniform optic characters over considerable areas. It is sometimes used to express a corresponding intergrowth of any two minerals, *e.g.*, plagioclase and orthoclase, augite and nepheline.

Microperthitic—Microperthite is the name given by Becke (Tschermak's Min. u. Pet. Mitth. 1882, IV., p. 197) to the so-called "*streifige*" orthoclase, the striated structure of which was shown by microscopic examination to be produced by the intimate intergrowth of a triclinic felspar (oligoclase or albite) with the orthoclase substance, thin lamellæ of the former being intercalated along orthopinacoidal or prismatic planes of the latter, as in the mineral perthite.

Microplacite—A term used by Schrauff for tabular microlites.

Migration-structur (*Ger.*)—A name given by Gümbel to the pseudo-fluxion structure shown by some diabase-tuffs (Schalsteine), in which crystalline needles and granules are arranged in bands or zones around the larger constituents. This structure is said by him to be caused by the alteration of old and development of new material, which thus constitutes a "migration" of mineral matter.

Mikrolithenfilz (*Ger.*)—A *felted* aggregate of microlites or slender needle-like crystals, such as is formed by the felspars of the groundmass of many rocks—notably the andesites.

Mimetic (*Ger.* mimetisch)—Tschermak proposed to call those crystals mimetic which possess externally a high degree of symmetry, but are built up by polysynthetic twinning of crystals having a low grade of symmetry. Thus chabasite is termed a mimetic rhombohedral crystal.

Moiré—The name given to the wavy appearance, comparable to that of watered silk, presented by thin plates of mica under crossed nicols.

Monoclinic—The name given to one of the six systems of crystals. It is characterized by one plane of symmetry. Its forms are referred to three unequal and dissimilar axes; of these one is at right angles to the other two, which cut one another obliquely.

Syn. Clinobasic, Clinorhombic, Monoclinohedral, Monosymmetric, Oblique, Zwei-und-eingliedrig.

Monogenous—A word applied by some authors to clastic rocks the fragments of which are derived solely from one rock. *See* Polygenous.

Monosomatic—A term applied to crystals and their inclusions when both belong to the same mineral species. *See* Disomatic.

Mörtelstructur (*Ger.*)—A term proposed by Törnebohm (Geol. Fören. Förhandl, 1881, V., p. 233), for a structure especially exemplified in certain gneisses. This structure is characterized by grains of felspar and quartz being cemented by a fine mortar of the same material.

Mylonitic—Prof. Lapworth (Brit. Ass. Report, Aberdeen, 1885, p. 1026), has suggested that finely laminated schists, which have been produced by a crushing, dragging, and grinding (in short, dynamic metamorphism) of the original rocks, should be termed *mylonites* (from *mylon*, the Greek for a mill). Such rocks are "composed of shattered fragments of the original crystals set in a polarizing cement of the secondary quartz" (and presumably felspar). The lamination is due to the presence of thin ribbon-like and tissue-like bands and fibres of mica and similar minerals. *See* Cataclastic structure.

Neck—The volcanic material which has accumulated around and in the pipes or funnels of ancient volcanic vents.

Needle (*Fr.* aiguille; *Ger.* Nädelchen)—A term used in petrography to denote the acicular prismatic forms in which many minerals, notably mesotype, occur in rocks.

Negative (optic)—*See* Elasticity of crystals.

Neovolcanic—Applied by Rosenbusch (Physiogr. der Massig. Gest., 1886, p. 6) to volcanic rocks of post-cretaceous age. *See* Palæovolcanic.

Neptunic—*See* Aqueous.

Netted structure (*Ger.* gestrickte-Structur)—In serpentines (antigorite-serpentines) which have been formed by the alteration of augite, the chemical change has proceeded along cleavage-cracks which cross one another at an angle of about 90°, thus producing a plexus of bladed forms which sometimes bears a resemblance to network. It is also known in Germany as "*Balken-struktur*." *See* Mesh and Lattice structure.

Nodule (*Ger.* Steinwulste, Schlangenstein)—Any irregular aggregation of rock-material, with or without a nucleus, which may be organic or inorganic. Flint and ironstone are substances which frequently form nodular concretions.

Ocellar-structur (*Ger.*)—*See* Centric Structure.

Octahedron—The simplest form in the regular system of crystals. Its eight faces are all equilateral triangles, each cutting the three axes at unit distance. The angle between any two adjacent faces measured across an edge is 109° 28′.

Oolitic (*Ger.* Roggensteinstructur)—A term applied to rocks composed of small spheroidal concretions which show, in most cases, both a radial and a concentric structure.

Opacite—A term employed by some authors to designate the opaque substances, occurring in many rocks, which do not admit of microscopic determination.

Opalescent—Exhibiting a play of colours similar to that of some varieties of opal.

Ophitic (*Ger.* diabasisch-körnig, divergent-strahlig-körnig)—The name given to a structure characteristic of many dolerites (diabases of the German) in which the augite appears under the microscope in plates extending over large areas, but penetrated and cut up into small portions by lath-shaped crystals and needles of felspar. The separated portions of the augites show, however, that they are in crystalline continuity by the possession of the same optic orientation. Other minerals have been observed to be associated in a similar manner. *Syn.* Granito-trachytic (v. Lasaulx).

Optic axis—The direction in anisotropic crystals in which a ray of light undergoes no double refraction. Crystals are termed *uniaxial* when they have one, *biaxial* when they have two such axes. Crystals belonging to the Tetragonal and Hexagonal systems are uniaxial, those belonging to the Rhombic, Monoclinic, and Triclinic, biaxial. In the former the optic axis coincides with the principal crystallographic axis. In the latter the position of the axes varies with the mineralogical composition of the crystal, sometimes even with the chemical composition of the mineral (as, for instance, in felspar); it is also influenced by the temperature (as in selenite).

Optic normal—The direction at right angles to the optic axial plane. It is coincident with the mean axis of elasticity. *Syn.* Third mean line.

Orbicular—A term applied to rocks (granites, gabbros, and diorites) which contain spheroidal concretions (*e.g.*, the Napoleonite of Corsica).

Organogenic—A term applied to rocks which are derived from organic substances. *See* Phytogenic and Zoogenic.

Orientation—This term has reference in microscopic petrography to the relative direction of crystal-axes, or of axes of elasticity, in two or more crystals; similarly oriented crystal sections extinguish simultaneously under crossed nicols.

Orogenetic—That which relates to the formation of mountains.

Orthodiagonal—The name sometimes given to the axis in the monoclinic system of crystals that is at right angles to the remaining two axes.

Orthopinacoid—One of the three principal crystallographic planes in the monoclinic system. It is parallel to the vertical and to the horizontal or ortho-axis. *See* Pinacoid.

Orthopyramid; Orthoprism; Orthodome—*See* Pyramid, Prism, and Dome respectively.

Orthorhombic—*See* Rhombic.

Oscillatory—When the faces of two different forms of the same order are alternately developed in a crystal, the result being a fine parallel striation, the combination is said to be oscillatory.

Outcrop—The term applied to the edge of a stratum as it is exposed at the surface of the earth. *Syn.* Basset.

Oxygen-ratios (*Ger.* Sauerstoff-quotienten)—G. Bischof first introduced the method of quoting rock or mineral analyses by oxygen ratios. These are obtained by dividing the oxygen of the bases by that of the silica. Thus:

$$\frac{xO \text{ (of monoxide)} + yO \text{ (of sesquioxide)}}{zO \text{ (of silica)}}$$

Palæovolcanic—Rosenbusch (Physiog. der Massig. Gest., 1886, p. 6) subdivides the group of volcanic rocks into paleovolcanic and neovolcanic, according as they are of pretertiary or postcretaceous age.

Panidiomorphic—Applied to rocks in which all the minerals present are idiomorphic (*q.v.*).

Panniform—A term sometimes used to designate the corrugated aspect of consolidated lava, which often similates the appearance of rumpled cloth.

Paraclase—*See* Joint and Fault.

Paragenesis—This term, introduced by Breithaupt (Die Paragenesis der Mineralien, Freiberg, 1849), embraces the laws regulating the association of minerals.

Parallel structure—That structure of rocks in which the mineral components or the differently constituted parts of the rock are arranged parallel to one another, the result being a more or less well-defined banding. Such parallelism may be due (1) to original deposition (*lamination*), (2) to differential movement before consolidation (*fluxion structure*), (3) to subsequent deformation by earth-stresses.

Parameter—The intercepts (measured from the origin) cut off from the axes of a crystal by one of its faces constitute the parameter of the latter.

Paramorphism—The name given by Stein to those pseudomorphous changes which take place without loss or gain of mineral substance. Synonymous with this term is the word *allomorphism*, proposed by Dana.

Paroptesis—A term suggested by Kinahan (Geology of Ireland, 1878) for contact-metamorphism.

Parting—A thin layer, coincident with the bedding-plane, of some soft rock between two harder beds. Along the separation thus produced the beds are said to "part." N.B. A thin layer of a *hard* rock between two softer ones is generally termed a seam.

The same word is used by G. H. Williams (Bull. of the U.S. Geol. Survey, No. 28, p. 22) to designate the lamellar separation (parallel to the orthopinacoid) of diallage. (*Ger.* Absonderung.)

Pegmatitic—A structure produced by an intimate intergrowth of two minerals of simultaneous formation. The pegmatitic intergrowth of quartz and felspar is familiar to all in the so-called graphic granite.

Pelitic (Naumann)—Having a texture like that of dried mud.

Perimorphism—Scheerer termed those crystals perimorphic which consist merely of a thin rind, the interior being filled with other minerals.

Perlitic—A rock structure especially characteristic of the rock known as perlite; also found in other vitreous, but never in holocrystalline, rocks. Thin sections of rocks possessing this structure show under the microscope a series of more or less imperfect curvilinear cracks. Besides these, rectilinear cracks are often present.

Petrogeny—That department of geology which treats of the formation of rocks.

Petrography—The science which treats of the mineralogical composition and minute structure of rocks.

Petrology (*Ger.* Gesteinskunde, Gesteinslehre)—The science which treats of rocks. *Syn.* Petralogy.

Petrosilex—A term employed by French petrographers to denote the cryptocrystalline groundmass of many felsites and porphyries, the chemical composition of which indicates an aggregate of quartz and felspar.

Pflock-structur (*Ger.*)—The word used by Stelzner (N.J. B.B., II., 1882, p. 369) to designate the micro-structure of some varieties of melilite. Sections of this mineral cut at right angles to the basal plane are sometimes seen under the microscope to be traversed transversely by curious bolt-, peg-, or oar-shaped bodies. There seems to be some doubt as to the nature of these *Pflöcke*. In fact, Stelzner himself could not decide whether to regard them as solid bodies or cavities.

Phanerocrystalline—A word used by some authors to embrace both *macro-* and *microcrystalline* (*q.v.*). It is thus opposed in meaning to *cryptocrystalline*.

Phanérogène—A French term for coarsely granular; used in contradistinction to *adélogène* (*q.v.*).

Phaneromerous—A term applied to coarse crystalline rocks. *See* Cryptomerous.

Phase—A term used in speaking of the consolidation of a rock to denote a periodicity of crystallization. The *first phase* is that in which the porphyritic minerals are separated; the *second*, that in which the groundmass consolidates. *See* "Recurrence of phase."

Phytogenic—Applied to rocks which are composed of the remains of vegetable matter.

Pilotaxitic—The name given by Rosenbusch (Mikros. Physiog. der massig. Gest., p. 466) to a holocrystalline structure especially characteristic of certain porphyrites and basalts. The groundmass of these rocks consists essentially of slender laths and microlites of felspar in felted aggregation, and often presents fluxion phenomena. If, in addition, films of glass are present, the structure is said to be *hyalopilitic*. The normal structure of the andesites is the hyalopilitic (Rosenbusch, *l. c.*, p. 673).

Pisolitic—The name given to an oolitic structure when the spheroidal concretions are at least of the size of a pea, as in the so-called *Erbsenstein* of Carlsbad and the Pea-grit of the Cotteswold Hills. *See* Oolitic.

Plan-parallel-structur (*Ger.*)—That structure of rocks which is produced by a parallel arrangement of minerals having a tabular, lamellar, or scaly development (*e.g.*, felspar, mica, talc). It may be original (lamination) or superinduced (schistosity or foliation).

Pleochroic Borders (*Ger.* pleochroitische Höfe)—In some, usually colourless, minerals a zone of strong pleochroism is found around certain mineral-inclusions. The phenomenon is often observed in andalusite. In polarized light this mineral appears colourless in certain positions; on rotation, however, a number of bright yellow spots spring into view, again disappearing on the rotation being continued. Mica often behaves similarly.

Pleochroism—The property possessed by pellucid doubly refractive minerals of transmitting rays of different colour or intensity in different directions. Uniaxial minerals are *dichroic*, since they possess two directions (parallel and normal to the chief axis) in which the greatest difference of colour is shown. Biaxial minerals, on the other hand, are *trichroic*, since they have three directions, corresponding to the three different axes of elasticity, along which rays of different intensity are transmitted. *Syn.* Polychroism.

Plexus—A network.

Plusiatic—A name sometimes applied to sands which are rich in ore or precious stones.

Plutonic—In petrography, applied to the deep-seated equivalents of volcanic rocks. The word *hypogenic* is sometimes used in this sense.

Poicilitic—*See* Lustre-mottling. Also applied to the New Red Sandstone series.

Polygenous—A word applied by some authors to clastic rocks which are composed of fragments derived from two or more different rocks. Used in contradistinction to *monogenous*. *Syn.* Polymikt.

Polymikt (*Ger.*)—*See* Polygenous.

Polymorphism—The property possessed by some substances of assuming two or more molecular structures. If the bodies crystallize, this difference is expressed in the different parametral values of the axes of the several crystalline forms. These bodies may be termed, with Tschermak, *heteromorphous* varieties of the same *polymorphous* substance. According to the number of heteromorphous varieties it is capable of assuming, a substance is *dimorphous*, *trimorphous*, &c. Carbonate of lime and titanic acid are examples of dimorphism and trimorphism respectively, the former occurring in nature as calcite and arragonite, the latter as rutile, anatase, and brookite. *Syn.* Pleomorphism.

Polysynthetic Twinning—Twinning in lamellæ; lamellar twinning; twin-lamellation; twin-striation.

Porodine—A term applied by Breithaupt to rocks which are composed of amorphous material and which have been produced by slow consolidation from a gelatinous condition; as for example, opal.

Porphyritic—This term is generally applied to any rock in which one or more of the mineral components dominate in size over the remainder, the latter constituting the *groundmass*. Rosenbusch, however, proposes to define "porphyritic structure" as that in which there is a recurrence of similar minerals, due to the rock having consolidated in two distinct phases.

Positive (optic)—*See* Elasticity of Crystals.

Pressure-metamorphism—*See* Mechanical metamorphism.

Prism—In crystallography this form may be treated as a special case of the pyramid, namely, that in which pyramidal planes cut the vertical axis at an infinite distance. This being the case, each kind of pyramid furnishes a prism, and so we have *proto-*, *deutero-*, *trito-*, *macro-*, *brachy-*, *ortho-*, and *clino*-prisms. *See* Pyramid.

Prismatic—As applied to minerals, a term indicating that they occur in acicular or columnar forms, such minerals giving lath-shaped sections. As applied to rocks it refers to their mode of jointing.

Promorphisme (*Fr.*)—*See* Devitrification.

Protogenic—A word applied by some authors, in contradistinction to *deuterogenic*, to the crystalline rocks of igneous origin.

Protopyramid; Protoprism. *See* Pyramid and Prism

Province (*Fr.* domaine)—A petrographical province is an area characterized by the constant appearance of a certain type of rocks.

Psammitic (Naumann)—Composed of small grains, as, for instance, sandstone.

Pseudomorphous—Applied to minerals possessing a crystalline form other than their own, which they have obtained by the displacement or alteration of the original mineral.

Pseudospherulite (*Fr.* étoilement)—A term applied to those belonospherites (spheroidal crystalline aggregates with radial structure) which consist of two or more easily distinguishable components. The granophyres often contain typical pseudospherulites. The rays composing these consist alternately of quartz and felspar.

Pseudostromatism—A word suggested by Bonney (Proc. Geol. Soc., 1886, p. 65) for the apparent bedding, parallel to cleavage foliation, sometimes produced in crystalline rocks as a result of pressure.

Pumiceous—Having the porous nature and vesicular appearance of pumice.

Puys (*Ger.* Kuppen)—The name given by the French to small conical hills piled up around minor volcanic vents.

Pyramid—A crystallographic form, of which each face cuts all three axes (the deuteropyramids form an exception to this rule). According to their parametral ratios the pyramids are classified as *proto*, *deutero*, and *trito* (in the tetragonal and hexagonal systems); *proto*, *macro*, and *brachy* (in the rhombic and triclinic); and *proto*, *ortho*, and *clino* (in the monoclinic).

Pyroclastic—A name given to fragmental igneous rocks (tuffs, &c.).

Pyrogenic—Of igneous origin. Often used synonymously with *igneous* (*q.v.*).

Quadratic—*See* Tetragonal.

Quartz auréolé (*Fr.*)—Applied by French petrographers to the quartz-crystals of certain felsophyric porphyries. These crystals are surrounded by a zone of slightly turbid substance which extinguishes simultaneously with the central crystal. The researches of Williams have shown that this zone consists essentially of quartz, in addition to which, however, a little felspar or microfelsite is present, the kaolinization of which produces the slight turbidity referred to above.

Quartzose—Rich in quartz.

Recurrence of Phase—In the consolidation of some rocks, notably those of porphyritic habit, there is a recurrence of phase in the order of crystallization; or, in other words, allied minerals are found at two distinct periods of consolidation. Those which are found first are generally large and well crystallized, and constitute the "porphyritic minerals" (*Ger.* Einsprenglinge); while those of the second generation are of smaller size, and make up the groundmass.

Regular—The name given to one of the six systems of crystals. It is characterized by the possession of nine planes of symmetry. The forms belonging to this system are referred to three equal and similar axes, standing at right angles to one another. *Syn.* Cubic, Octahedral, Tesseral, Tessular, Isometric, Monometric.

Reticulated—Having the appearance of network; traversed by two sets of parallel lines.

Rhombic—The name given to one of the six systems of crystals. It is characterized by three planes of symmetry. The forms of the rhombic system are referred to three unequal and dissimilar axes, which stand at right angles to one another. Any one of these may be taken as the vertical axis. *Syn.* Orthorhombic, Prismatic, Anisometric, Trimetric, Ein-und-einaxiges.

Rhombic dodecahedron—One of the forms belonging to the regular system of crystals. It is contained by twelve equal and similar rhombs (the diagonals of which bear to one another the ratio of $1 : \sqrt{2}$). Each face cuts two axes at unit distance and is parallel to the third. Six planes of symmetry of the regular system coincide in direction with the rhombic dodecahedral faces.

Rhombohedral—*See* Hexagonal.

Rhombohedron—The rhombohedra are the hemihedral forms derived from the hexagonal protopyramids by the disappearance of alternate faces—three at the top, and three at the bottom. Two series of rhombohedra, differing only in position, are thus obtained. One of these is known as the positive, the other as the negative, series.

Rock (*Fr.* roche; *Ger.* Gestein, Felsart, Erdglied, Gebirgsart)—An aggregate of one or more mineral substances, possessing a more or less definite and persistent geological character, which is maintained over some considerable area. Ore and mineral veins, vein-stones, &c., are mineral aggregates; but these differ from rocks in not being characterized by invariability as regards structure and substance.

Saccharoid—Applied to crystalline limestones and other rocks which have a texture resembling loaf-sugar.

Salband (*Ger.*)—A thin crust at the margin of a dyke or vein.

Scale (*Fr.* écaille; *Ger.* Blättchen, Schüppchen)—A minute lamina. Mica, chlorite, and kaolin are examples of minerals which occur in scales.

Scalenohedron—The scalenohedra are the hemihedral forms derived from the dihexagonal pyramids by the disappearance of alternate pairs of faces. Two series of scalenohedra are thus obtained, which differ only in position from each other. They are known respectively as the positive and negative series.

Schiller (*Ger.*)—The submetallic lustre given by the crystals of some minerals (bronzite, hypersthene, &c.) when held in certain positions.

Schillerization—The name given by Prof. Judd (Q.J.G.S., XLI., 1885, p. 383) to a change which the mineral constituents of deep-seated rocks undergo. According to Judd this consists "in the development along certain planes within the crystal of tabular, bacillar, or stellar enclosures, which give rise to the peculiar phenomena expressed by the term schiller."

Schiller-plane—A plane in a crystal in which occur the enclosures giving rise to the phenomenon of schiller.

Schistosity (*Ger.* schieferig)—This term denotes the fissility of the crystalline schists—usually, if not always, the result of mechanical metamorphism.

N.B.—It should be remembered that some authors use the term schistose simply in the sense of fissile. Thus, according to them, slate would be a schistose rock.

Schliere (*Ger.*)—A word much used by German petrographists to denote the streaks and bands produced by differential movements in rock-magmas.

Scoriaceous—Having the cindery appearance of scoriæ.

Scoriæ—Fragments of lava having a cindery aspect.

Secondary (*Ger.* secundär, neugebildet)—This word, as used in petrography, is applied to minerals which are derived from the alteration of the original constituents of a rock.

Secondary Felspar—By the action of mechanical metamorphism, the original felspars of a rock often undergo a regeneration the nature of which is not yet understood. Under the microscope the remaining portion of the old kaolinized felspar-grain is sometimes found surrounded by a layer of fresh colourless granules, which in isolated cases show twin-striation. Lossen regards the secondary felspar of many of the diabases of the Hartz as albite.

Secretionary—A term used to express a growth from without inwards, in contradistinction to *concretionary*, which signifies growth starting from a central point or nucleus and proceeding outwards.

Segregation-vein—A vein which has been produced by the segregation of the component mineral matter of a rock along fissures.

Semicrystalline—A term applied generally to eruptive rocks which are composed partly of crystalline, partly of amorphous matter. This term was also used by Naumann to designate clastic rocks in which there is a predominance of a crystalline cement.

Septaria—The name given to concretionary nodules, often lenticular, occurring in clays. Such nodules show, in the interior, cavities and cracks (*septa*), which are empty or filled with secondary mineral substances.

Shaly—Exhibiting the fissile laminated character of a shale.

Shearing—Differential movement in a rock-mass. When the movement is concentrated along a plane, this plane is said to be a shear-plane.

Sheet (*Fr.* nappe; *Ger.* Decke, intrusives Lager)—Any eruptive mass which has spread out over a large area, or has been intruded between strata so as to appear at the surface as a bed.

Siliceous—Rich in silica.

Sigmoidal—Having the form of an *S*. Slowly moving lava streams often assume an internal sigmoidal structure, the folds produced by the unequal movement of the different parts of the mass having this form. A similar character is sometimes developed in foliated rocks which have been subjected to dynamic metamorphism. *See* "Ausweichungsclivage."

Skeleton-crystals (*Ger.* Krystallskelette, gestrickte Formen)—The incipient forms of crystallization in which some minerals, notably felspar, appear when the consolidation of the rock has been rapid. See Fig. 7 of text.

Slaty—Having the cleavable structure of a slate; applied also to fissile limestones which admit of being split up into smooth slabs.

Slickensides (*Ger.* Rutschflächen, Reibungsflächen, Scheifflächen, Spiegelflächen, Harnische)—The name given to the grooved and polished surfaces of rocks produced by the friction of the walls of a fault or joint during displacement.

Solution-plane (*Ger.* Lösungsfläche)—The name proposed by von Ebner (S. A. W., 1884, p. 368) for a plane in a crystal along which it is most easily attacked when submitted to chemical action.

Sphenoid—The sphenoids are the hemihedral forms derived from the tetragonal or rhombic protopyramids by the disappearance of alternate faces. Two series of sphenoids, differing only in position, are thus obtained. These are known respectively as the positive and negative series. The tetragonal sphenoid resembles the tetrahedron, from which it differs only in the inequality of its axes.

Spheric structure (*Fr.* structure globuleuse; *Ger.* sphärische or kuglige Structur)—An arrangement of the constituent particles of a rock around certain centres so as to produce radiate, concentric, or granular spheroidal aggregates. It embraces the following structural varieties: oolitic structure, variolitic structure, centric structure, spherulitic (felsospheric) structure; further, globospheric, belonospheric, and granospheric structure (*q.v.*).

Spherocrystal—A term applied to those belonospherites consisting of only one mineral in radiating fibres or needles.

Spheroid—The name given to the ball-shaped concretionary bodies occurring in certain orbicular granites and granitic rocks (*e.g.*, the Napoleonite of Corsica).

Spheroidal structure—The name given to the property possessed by certain igneous rocks (basalt, phonolite, &c.) of weathering into ball-shaped masses, each of which is usually made up of concentric layers. This phenomenon is connected with the contraction undergone by the rock during cooling.

Spherulitic structure (*Fr.* texture globulaire)—Peculiar to vitreous rocks, and so called because of the small spherular bodies (*spherulites*) they contain. The latter, viewed in thin section under a microscope, are seen to possess a divergent fibrous structure, and show, under crossed nicols, the characteristic black cross.

Spicule—A small dart-shaped body; a term sometimes applied to minerals occurring in that form.

Stellate (*Ger.* sternförmig)—Radiating from a centre, as some fibrous minerals (*e.g.*, actinolite).

Strain-slip cleavage—*See* Ausweichungsclivage.

Stratification foliation—Foliation in which the minerals are arranged parallel to the stratification of the rock.

Stratigraphy (*Fr.* and *Ger.* Stratigraphie)—That department of geology that treats of the relative disposition of strata, and of the disturbances they have undergone subsequent to deposition.

Stratum (*Fr.* couche, strate; *Ger.* Schicht)—The name given to the layers (strata) in which aqueous rocks are deposited. It is the lowest subdivision in the classification recommended by the International Geological Congress at the Bologna meeting (1881). According to this scheme—

Strata unite to form an assize, or beds;
Assizes to form a stage (*Fr.* étage; *Ger.* Stufe);
Stages to form a series, or section (*Fr.* séries; *Ger.* Abtheilung);
Series to form a system (*Fr.* terrain; *Ger.* System);
Systems to form a group (*Fr.* groupe; *Ger.* Gruppe).

Streckung (*Ger.*)—The German expression for the extension of the components of a rock along parallel lines, whether it be due to differential movements in the molten magma or to the mechanical deformation of the solid rock. *Syn.* Linear-parallel structur.

Striated (*Fr.* strié; *Ger.* gestreift)—Marked with fine parallel straight lines, as the triclinic felspars; applied also to rocks which have been scored by ice action.

Strike—The strike of a bed is the direction (expressed by reference to the points of the compass) of the line formed by the intersection of the plane of the bed with the plane of the horizon.

Stylolites—A curious structure found in certain limestones, dolomites, and marls. It consists of an arrangement of irregular cylindrical bodies which stand at right angles to stratification and are often abruptly terminated.

Subaërial—Applied to phenomena which take place on the earth's surface, in contradistinction to those which take place under water, these being termed *subaqueous*.

Subaqueous—Applied to rocks deposited under water.

Subsequent—A word used by some authors synonymously with *intrusive* (*q.v.*).

Synchronous—Of the same age.

Synclase—*See* Joint.

Synclinal—A term applied to strata which dip towards a central axis. *See* Anticlinal.

Tabular structure—The bedded structure observed in many igneous rocks, and caused by well-defined horizontal joints.

Talcose—Of the nature of talc, or containing a large proportion of that mineral.

Tautozonal—The name given to the faces of crystals which lie in one and the same zone.

Tetartohedral—The term applied to crystals which present only a quarter of the full number of faces, the others having disappeared in accordance with some law of symmetry.

Tetragonal—The name given to one of the six systems of crystals. It is characterized by five planes of symmetry. The forms of the tetragonal system are referred to three axes standing at right angles to one another, two of which are equal and similar, the other (the chief axis) unequal and dissimilar. *Syn.* Quadratic, Pyramidal, Prismatic, Dimetric, Monodimetric, Zwei-und-einaxiges.

Tetrahedron—The hemihedral form derived from the regular octahedron by the disappearance of its alternate faces. The figure which thus results is enclosed by four equilateral triangles. Since there are two different sets of faces, either of which may be made to vanish, two different tetra hedra are possible and occur in nature. These are distinguished from one another by the one being termed positive, the other negative.

Tetrakishexahedron—The tetrakishexahedra are a series of forms in the regular system contained by twenty-four isoceles triangles, the limits of which are formed by the cube and the rhombic dodecahedron respectively. Each face cuts one axis at unit distance, one at a distance equal to a rational quantity, m, and is parallel to the third. *Syn.* Pyramidal Cube.

Texture—The French are inclined to apply the word *structure* to the nature of the form assumed by a rock on consolidation ; whereas the word *texture* is applied to the size and mutual arrangement of the constituents of the rock. In Germany and England, however, these words are used more or less indifferently.

Thrust-plane—Term applied to a reversed fault which is only slightly inclined to the horizon.

Thalassic—A term applied to sedimentary rocks which are laid down on the sea-bottom.

Trachytic—A structure characteristic of volcanic rocks, in which the minerals occur in lath-shaped crystals and microlites, frequently showing fluxion-structure. The name was originally given to these rocks on account of their rough texture. *Syn.* Trachytoid, Pilotaxitic.

Translucent—Applied to minerals which allow light to pass through them without being perfectly transparent.

Trappean—The word trap, as used by the older writers, had no very precise signification; it appears to have been applied to all igneous rocks which occurred in *step*-like masses. Geikie (Q.J.G.S., 1871, p. 280) proposes to use it as a "convenient synonym for truly volcanic rocks which are found in Paleozoic, Secondary, or Tertiary formations."

Triakisoctahedron—The triakisoctahedra are a series of forms in the regular system contained by twenty-four isosceles triangles, the limits of which are formed by the octahedron and the rhombic dodecahedron. Each face cuts two axes at unit distance, the third at a distance equal to a rational quantity *m*, greater than unity. *Syn.* Pyramidal octahedron.

Trichite—A name proposed by Zirkel (Mikros. Beschaf., 1873, p. 89), for *hair*-like crystallites which occur often in curiously bent, curved, or twisted forms in vitreous rocks.

Trichroism—*See* Pleochroism.

Triclinic—The name given to one of the six systems of crystals. There is no plane of symmetry, and the forms of this system are referred to three unequal and dissimilar axes, all cutting one another obliquely. *Syn.* Asymmetric, Anorthic, Triclinohedral, Doubly Oblique, Ein-und-eingliedrig.

Trimorphism—*See* Polymorphism.

Tritopyramid; Tritoprism—*See* Pyramid and Prism.

Tufted (*Ger.* büschelförmig)—Applied to microlites and fibres occurring in bundles or tufts. *Syn.* Fascicular.

Twinned (*Fr.* hémitrope, maclé; *Ger.* verzwillingt). A crystal is twinned when two portions of the same individual or two different individuals are grown together in such position that a revolution 180° is necessary to bring them into complete parallelism. The axis of rotation is termed the twinning axis; and this is normal to the twinning plane, which must be a possible face of the crystal.

Care must be taken not to confound the twinning-plane with the face of composition, the latter being a plane common to both individuals.

Unconformity (*Ger.* discordante Auflagerung)—A term used in stratigraphy to express an interrupted relation between two sets of beds, the upper series having a different strike and dip from that of the lower. Such unconformity may be brought about either by the earlier deposited strata being upheaved and denuded or by their being denuded without upheaval, before the later beds were laid down.

Uniaxial—*See* Optic Axis.

Vacuole—The name given to the minute amygdaloidal cavities, filled with decomposition-products, found in variolite.

Variole—The name given to spheroidal bodies, varying in size from a pin's head to a pea, which are found projecting from the weathered surface of variolite (the altered marginal portion of diabase). They are very differently constituted, consisting sometimes of radiating fibres of some actinolitic mineral, sometimes of felspathic material, with or without pyroxenic or hornblendic granules.

Variolitic—A name given to a rock-structure which is characterized by the presence of numerous spheroidal bodies as in variolite. *See* Variole.

Vein (*Fr.* filon; *Ger.* Gang, Trumm)—A general term for any mass of mineral matter filling up a crack or fissure. Geologists distinguish between mineral veins, eruptive veins, and segregation veins.

Vesicular—A term applied to cellular volcanic rocks, when the holes are few and small.

Viridite—A term used to designate the green decomposition-products, characteristic of the altered basic rocks, which do not admit of exact determination.

Vitreous—Of the nature of glass.

Vitrophyric—A term applied to those quartz-porphyries whose groundmass is composed essentially of glassy matter, with or without microlites and crystallites.

Volcanic—A term used in petrography, in contradistinction to *plutonic*, to designate such rocks as have consolidated at or near the surface. *Syn.* Effusive.

Weathering (*Ger.* Verwitterung)—The changes in the substance of a rock produced by surface agencies.

Xenomorphic—*See* Allotriomorphic.

Zone—In crystallography, a group of faces which are parallel to one and the same straight line (*zone-axis*). Such faces are said to be *tautozonal*. A plane perpendicular to the zone-axis is the *zone-plane*. In stratigraphy, a bed or series of beds characterized by an assemblage of fossils of which one species is taken as the index; as, for example, the ammonite-zones of the Lias.

Zoned, Zonal—A structure exhibited by felspar and other minerals in which the growth of the crystals is marked by bands or zones of inclusions or a change in composition (*Ger.* Schalenbau, isomorphe Schichtung). Another case of zoning is when one mineral is completely surrounded by a narrow band or zone of a second.

Zoogenic—Of animal origin, as, for instance, the coral reefs.

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KEY PLATE I

FIG I

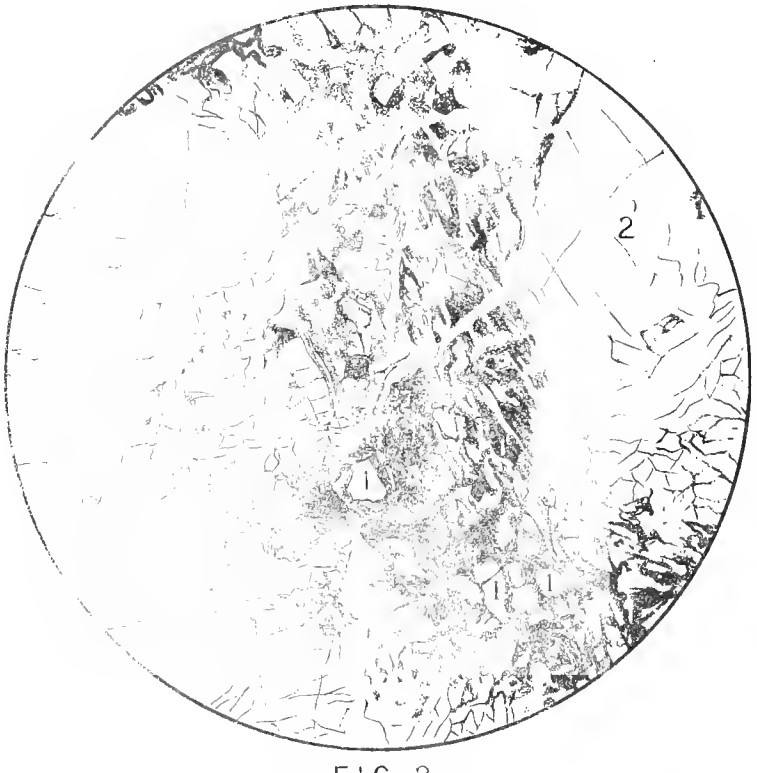


FIG. 2

PLATE I.

FIG. I.

LHERZOLITE.

SEM NEAR VICDESSOS, PYRENEES.

Magnified 25 Diameters. Ordinary light.

The essential constituents of this rock are olivine (1), enstatite (2), chrome-diopside (3), and chrome-spinelle or pleonaste (4).

In the perfectly unaltered rock here figured it is sometimes difficult to distinguish between olivine and enstatite. Both minerals are perfectly colourless; but, as a rule, the olivine sections give higher tints in Newton's scale, when viewed under crossed nicols, than the enstatite. Where cleavages have been developed, as in the crystalline grain represented in the upper part of the figure to the left, the enstatite may be readily distinguished by its optical properties. The olivine forms about two-thirds of the entire rock. It is traversed by irregular cracks and bands of inclusions as shown in the figure. Under a high power the inclusions are seen to possess a peculiar vermicular form. The chrome-diopside may be distinguished in the original slide by a very faint greenish tinge which, however, is not represented in the figure, and also by its cleavages and optical properties.

The dull green mineral is chromite, picotite or possibly pleonaste. Chromite and picotite, the common minerals of this group occurring in the peridotites, are usually yellow, brown or reddish-brown. Pleonaste is green. The colour may therefore indicate that in the case here figured the mineral in question is pleonaste. The rock is holo-crystalline and granitic in texture. The individual minerals do not show definite external form.

FIG. II.

SERPENTINE.

BETWEEN KYNANCE COVE AND LIZARD TOWN, CORNWALL.

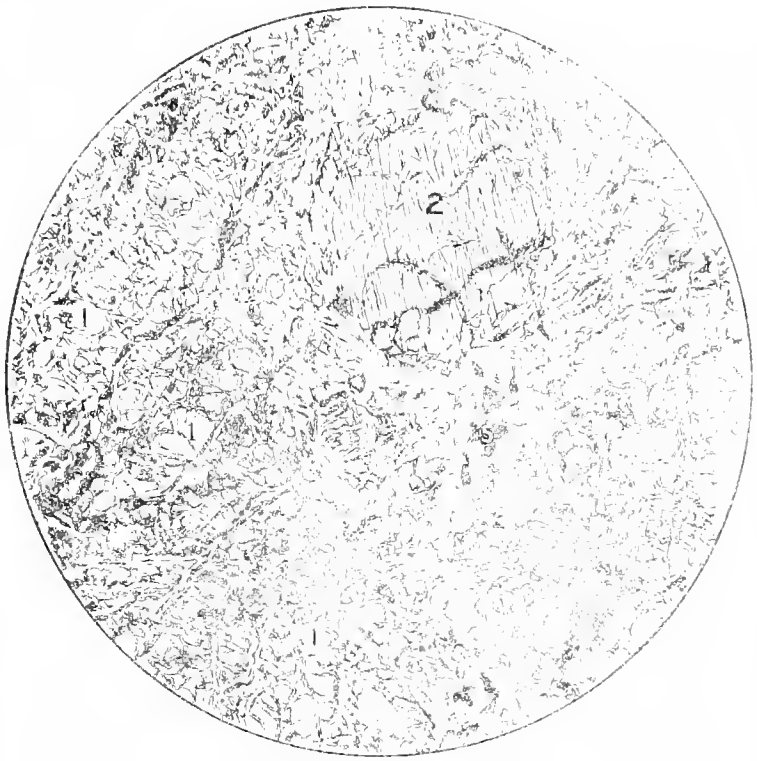
Magnified 25 diameters. Ordinary light.

In addition to the serpentine-substance, which is either green or colourless, unaltered grains of olivine (1), and a crystal representing the bastite-modification of enstatite or bronzite (2) may be detected.

The alteration of the olivine has taken place along the irregular cracks which traversed the original grains. The brown colour represents the hydrated ferric oxide which has been precipitated along these cracks by oxidising agents. The irregular network (maschen-structur), characteristic of serpentine produced by the alteration of olivine, is well represented in the lower and upper parts of the figure by the distribution of the ferric oxide.

KEY PLATE 2.

FIG 1



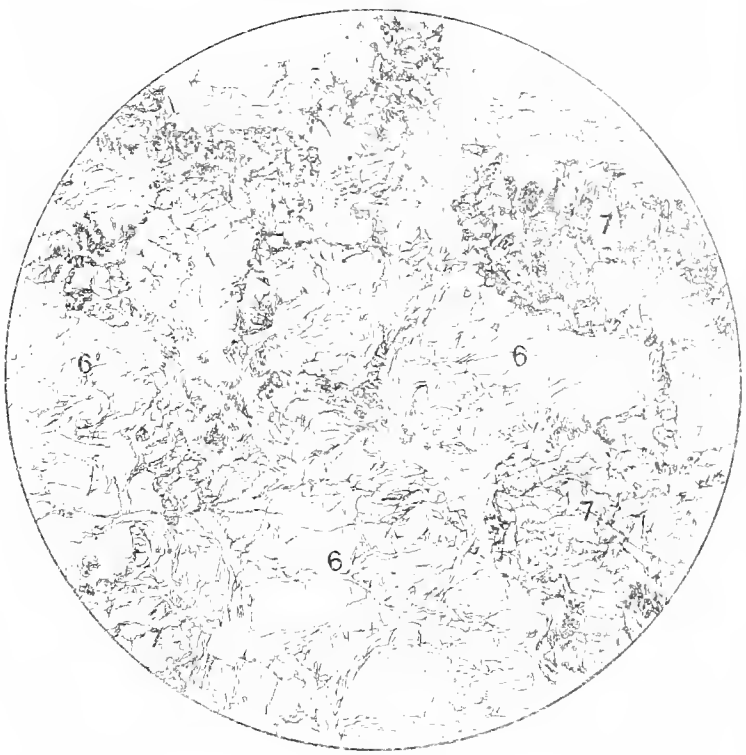


FIG 2.

PLATE II.

FIG. I.

SERPENTINE.

COVERACK COVE, CORNWALL.

Magnified 25 diameters. Ordinary light.

This figure shows, in addition to the serpentine-substance, a large amount of unaltered olivine (1) occupying the central portions of the meshes of serpentine. Adjacent grains of olivine extinguish simultaneously over large portions of the slide, as the stage is rotated between crossed nicols, thus showing that they are parts of one and the same original crystal, and that their present isolation is merely the result of the development of serpentine along original cracks.

The greenish yellow serpentine-substance may be resolved under the microscope, by the use of a high power, into fibrous or scaly aggregates which, under crossed nicols, sometimes give a faint but definite reaction, extinguishing light parallel with the axes of the fibres, and sometimes appear isotropic. The serpentine-substance is often coloured along the cracks by the presence of hydrated ferric oxide.

The slide illustrates the relative order in which the minerals of peridotites are affected by the agents producing serpentine. Thus the olivine is seen to have been much more affected than the pyroxene. (2) When the latter mineral is examined under a high power it is seen that the alteration commences along cracks and is indicated by a very fine parallel striation which runs outward from the cracks into the clear substance of the crystal to a greater or less extent.

The opaque black substance (5), seen below the comparatively unaltered pyroxene, is magnetite.

FIG. II.

PICRITE (?).

MENHENIOT, CORNWALL.

Magnified 25 diameters. Ordinary light.

This figure shows serpentinous pseudomorphs after olivine (6), augite (7) and magnetite. The augite when examined under a high power occasionally shows the lamination characteristic of diallage. Adjacent portions extinguish in the same position, showing that they belong to large ophitic masses.

Under a high power the greenish yellow serpentine-substance is seen to contain minute colourless microlites which appear needle-shaped, fusiform, lozenge-shaped, or lath-shaped in different sections. The long sections give a maximum extinction of about 17°. Rosenbusch (Massige Gesteine, p. 530) doubtfully refers these forms to a grammatite-like amphibole. The lozenge-shaped sections sometimes correspond to cross sections of the hornblende prism, and this confirms the suggestion of Rosenbusch. The microlites are sometimes arranged in two directions, more or less at right angles to each other. They are too minute to be represented in the figure.

Lath-shaped sections of pseudomorphs after felspar are sometimes seen to penetrate the ophitic plates of augite. The affinities of the rock may be indicated by describing it as having been originally an ophitic dolerite (diabase), in which olivine was present in great abundance and felspar only to a very small extent.

KEY PLATE. 3.

FIG. 1

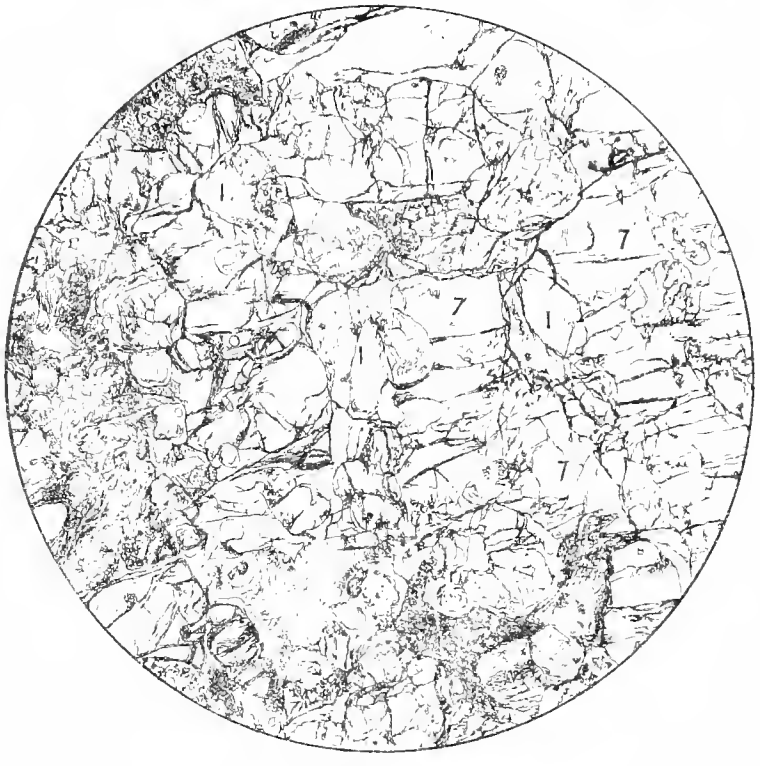


FIG. 2.

PLATE III.

FIG. I.

AUGITE-PICRITE.

SHIANT ISLES, WEST OF SCOTLAND.

Magnified 25 diameters. Ordinary light.

The original minerals here represented are olivine (1), augite (7) and magnetite. The secondary substances are serpentine after olivine (6), and a turbid material, which gives aggregate polarisation under crossed nicols, and probably represents an alteration product after felspar.

The olivines occur in more or less rounded grains. Those represented in the lower part of the figure have been partially converted into serpentine.

The augite is a rich reddish brown colour in moderately thick sections. The whole of this mineral represented in the figure extinguishes in one position as the stage is rotated between crossed nicols; thus showing that it belongs to one crystalline individual. It is entirely destitute of crystalline form.

FIG. II.

ANOTHER PORTION OF THE SAME SLIDE.

Magnified 25 diameters. Nicols crossed.

The minerals represented are olivine (1), plagioclase felspar, probably labradorite or bytownite (10), and magnetite.

The section is thick, so that the plagioclase gives brilliant colours of the first and second orders instead of polarising in neutral tints as is the case in sections of the usual thickness.

The olivines either give the brilliant greens and pinks of the higher orders (sometimes of the fourth order), or else appear dark in consequence of being at or near the position of extinction.

The felspar shows the lamellation characteristic of twinning on the albite plan. It will be observed that the felspar occurs in the form of large plates without any definite external faces, and that a large number of olivines are included in one and the same felspar individual. The rock is holo crystalline, and both the felspar and augite form, as it were, the groundmass in which the crystals and grains of olivine are embedded. This rock is one of the series described by PROF. JUDD in his paper on the "Tertiary and Older Peridotites of Scotland." (Q.J.G.S., Vol. XLI., p. 393).

KEY PLATE 4.

FIG. 1.

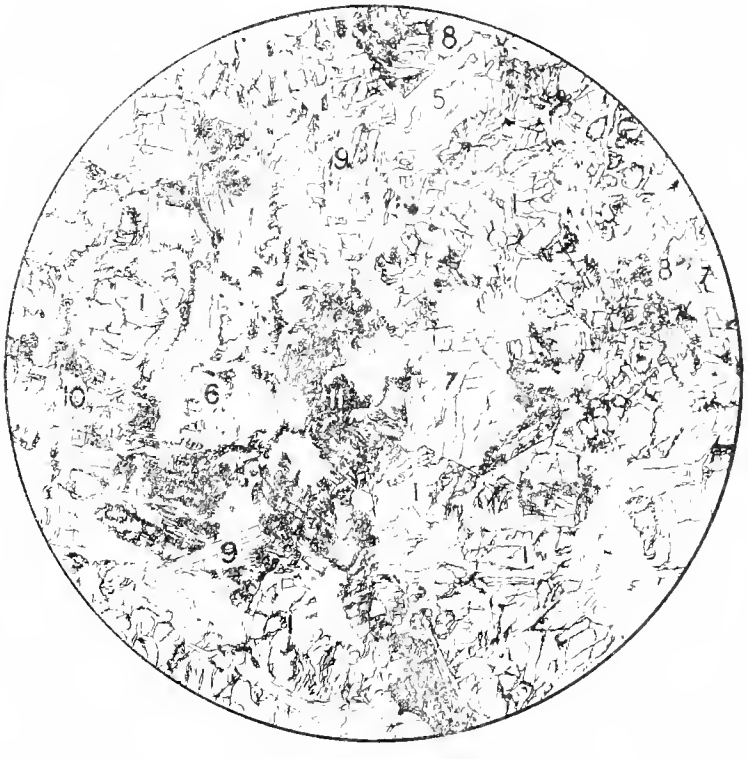


FIG. 2.

PLATE IV.

FIG. I.

HORNBLENDE-PICRITE (BONNEY). BOULDER, PEN-Y-CNWC, ANGLESEA.

Magnified 50 diameters. Ordinary light.

The portion of the slide represented in the figure is mainly occupied by a single individual of brown hornblende (8). The traces of the two sets of cleavage planes are nearly parallel, showing that the section lies approximately in the zone of the vertical axis. One important feature of the hornblende of this slide is that certain portions of it are green or colourless (8ª). Under crossed nicols the brown portion represented in the figure gives the blue of the second order, whereas the colourless portion gives the yellow or orange of the same order. In other portions of the slide a perfectly gradual transition from the brown through the green to the colourless variety may be observed; and in such cases the interference colours under crossed nicols are seen to rise in NEWTON'S scale as the colourless condition is approached. The positions of extinction are not affected by the change in colour.

The greenish patches (6) represent serpentinous pseudomorphs.

The black grains are somewhat translucent at the edges, and therefore probably belong to chromite or picotite.

The rock from which this slide is taken is described by PROF. BONNEY (Q.J.G.S., Vol. XXXIX. p. 254).

FIG. II.—AUGITE-PICRITE.—INCHCOLM, FIRTH OF FORTH.

Magnified 25 diameters. Ordinary light.

The original minerals are olivine (1), augite (7), biotite (9), hornblende (8), felspar (10) and magnetite or ilmenite (5). The secondary substances are yellow and green serpentine (6), and alteration products after felspar (11).

Olivine is by far the most abundant mineral. It occurs in the form of well marked crystals, and also as grains. In some varieties of the rock it is entirely changed to yellow or green serpentine.

The augite is usually a pale reddish brown by transmitted light. A cross section of an augite prism, similar to the one represented in the central portion of the figure, always shows an optic axis when viewed with convergent polarised light. The corresponding section of a rhombic pyroxene shows a positive bisectrix.

Sections of the biotite parallel with the vertical axis of the crystal change in tint as the stage is rotated over the polariser from a deep rich brown when the short axis of the nicol lies parallel with cleavages, to a pale brown when the short axis is at right angles to the cleavages. Basal sections show, of course, no pleochroism.

The hornblende is the rich brown variety commonly known as "basaltic hornblende." It occurs on the borders of the augite, as may be seen in the crystal on the right-hand margin of the figure only part of which is included within the field of view.

Plagioclase felspar is present only in very subordinate quantity, and in some varieties of the rock appears to be entirely absent. Unaltered felspar is rare, but a small portion is represented near the left-hand margin of the figure. The turbid aggregate near the central portion of the figure is probably due to the alteration of felspar. Some of the grains of this aggregate give brilliant colours under crossed nicols, and probably belong to a mineral of the epidote group.

The right-hand portion of the augite near the centre of the figure is penetrated by a lath-shaped section of a pseudomorph after felspar; thus showing that the rock is allied to the ophitic olivine-dolerites, and belongs to the same type as the rock from Menheniot. (Plate II., Fig. 2).

The rock was first described by Dr. A. GEIKIE (Trans. Roy. Soc., Edinburgh. Vol. XXIX., 1880, pp. 507, 508).

KEY PLATE. 5.

FIG. 1

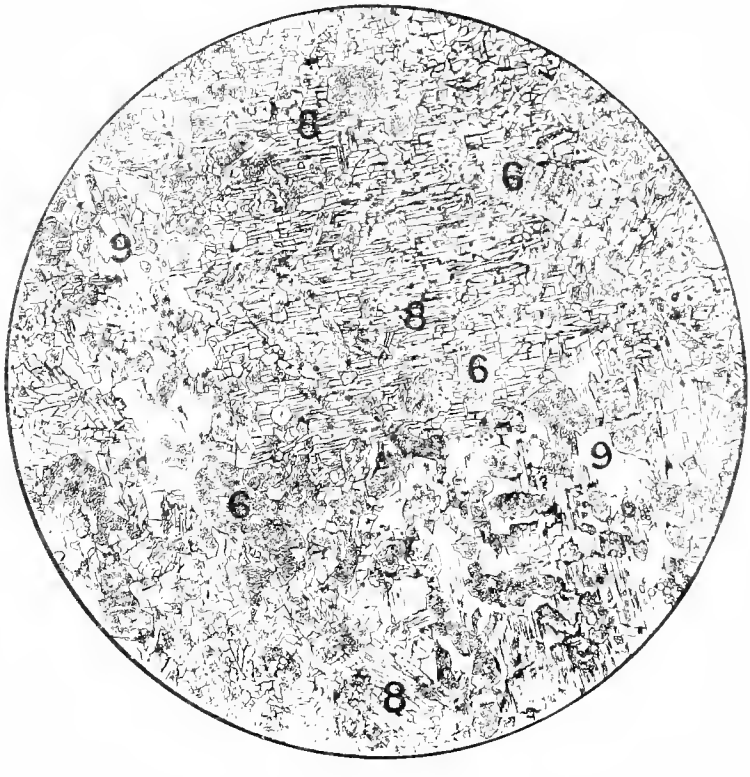


FIG. 2.

PLATE V.

FIG. I.

PICRITE.

HALIVAL. ISLE OF RUM.

Magnified 27 diameters. Ordinary light.

The minerals represented are olivine (1), green augite (7), and magnetite.

The olivine occurs in the form of rounded grains. It contains numerous minute opaque inclusions, which produce a cloudy aspect in certain places. The irregular cracks which traverse the grains are sometimes marked out by a brown staining.

The green augite forms, as it were, the ground mass in which the olivine grains are embedded, and possesses no definite external form. The portions in the upper part of the figure extinguish simultaneously, and are thus seen to be parts of one and the same crystalline individual. These portions show two sets of cleavage cracks, which intersect approximately at right angles, and give in convergent light an optic axis. The section is, therefore, taken nearly at right angles to the vertical axis.

Magnetite occurs in the form of crystals, and more or less rounded grains.

Other portions of the same slide contain olivine grains embedded in large plates of felspar (see plate III., fig. 2), and the latter mineral is somewhat too abundant to make the rock a true picrite.

This rock is one of those referred to by Professor JUDD (Q.J.G.S., vol. XLI., p. 389).

FIG. II. - SCYELITE.—ACHAVARASDALE MOOR, CAITHNESS.

Magnified 10 diameters. Ordinary light.

This figure shows hornblende (8), mica (9), serpentinous pseudomorphs after olivine (6), and magnetite.

The hornblende occurs usually in large crystalline plates, interrupted by the serpentinous pseudomorphs. The colour is very slight (α almost colourless; β and γ pale green). In the left hand portion of the figure aggregates of imperfectly developed hornblende crystals may be observed. In other portions of the figure, transitions from green to colourless hornblende with the usual rise in the order of the tint under crossed nicols may be observed.

The biotite also occurs in large plates. Sections at right angles to the basal plane show the characteristic cleavage and change in tint when rotated over the polariser, from a pale to a somewhat darker brown: but the dichroism is not strongly marked. Cleavage flakes of this mica, when examined with convergent light, give the interference figure of a mineral which is practically uniaxial. Minute tabular or rod-like inclusions of magnetite, arranged parallel to the planes of easy cleavage, occur in certain portions of this mineral; as, for example, in the lower part of the figure to the right.

The serpentinous substance is grass green in colour, and more or less cloudy, in consequence of the presence of minute opaque granules, tables or rods. The rod-like inclusions are often arranged in parallel planes. In some cases the structure of the serpentinous substance suggests that it is the result of the alteration of enstatite rather than olivine. Magnetite is scattered throughout the slide, mostly in the form of opaque granules and irregular patches.

This rock has been described by Professor HEDDLE (M.M., vol. V., 1884, p. 260,) and by Professor JUDD (Q.J.G.S., vol. XLI., p. 401). It bears a close relation with the hornblende picrite of Schriesheim, the principal difference being that the mica is much more conspicuous in the scyelite.

KEY PLATE 6.

FIG. 1.

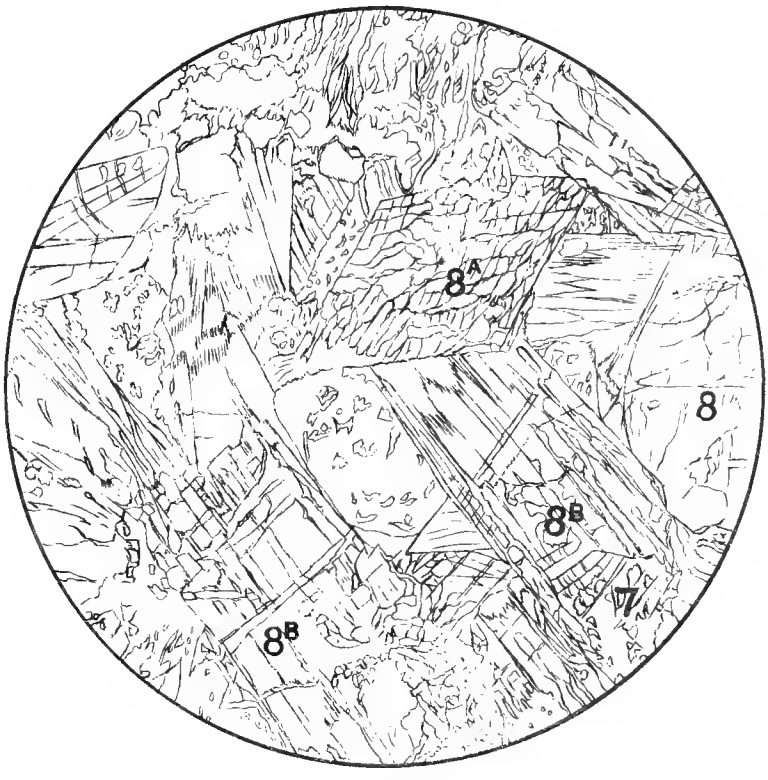


FIG. 2.

PLATE VI.

FIG. I

HORNBLENDE-PICRITE (BONNEY.)

TY CROES, ANGLESEA.

Magnified 50 Diameters. Ordinary light.

The two figures on this plate are intended to illustrate some of the characters commonly observed in the hornblende of this group of rocks.

The portion of the slide here represented is composed of hornblende in various conditions (8), a colourless pyroxene (7) and a colourless substance forming a sort of groundmass and composed of an aggregate of fibres and scales which give a definite, though not very strong reaction with polarised light.

Near the central portion of the figure (8^a) is a cross-section of a hornblende-prism. Portions of it have a decided brownish tint not represented in the figure. These portions shade into others which are green, and these again into others which are perfectly colourless. In the lower part of the figure to the right two vertical sections of hornblende (8^b) are represented. These also illustrate the transition from the green to the colourless variety. The colourless portions, moreover, are here seen to shade off into the colourless substance which forms, as it were, the groundmass. Under crossed nicols a considerable amount of calcite dust may be recognised at the points where the hornblende loses its individuality.

In other portions of the slide a colourless pyroxene may be recognised. The only section of this mineral in the figure (7) occurs as an inclusion in the hornblende on the lower right-hand margin.

FIG. II.

The same under crossed nicols.

The change in the colour of the hornblende is here seen to be accompanied by a rise in the order of the tint given under crossed nicols. The indigo of the second order shades gradually into the yellow of the same order. This of course indicates an increase in the double-refracting power of the mineral. The different portions of the hornblendes (8^b) extinguish simultaneously at an angle of 22°. The colourless substance into which the hornblende-fibres fade away sometimes contains brilliantly polarising fibres (c). Calcite dust (d) occurs in patches in different parts of the slide.

The rock is described by PROF. BONNEY (Q.J.G.S., Vol. XXXIX., p. 254).

KEY PLATE 7.

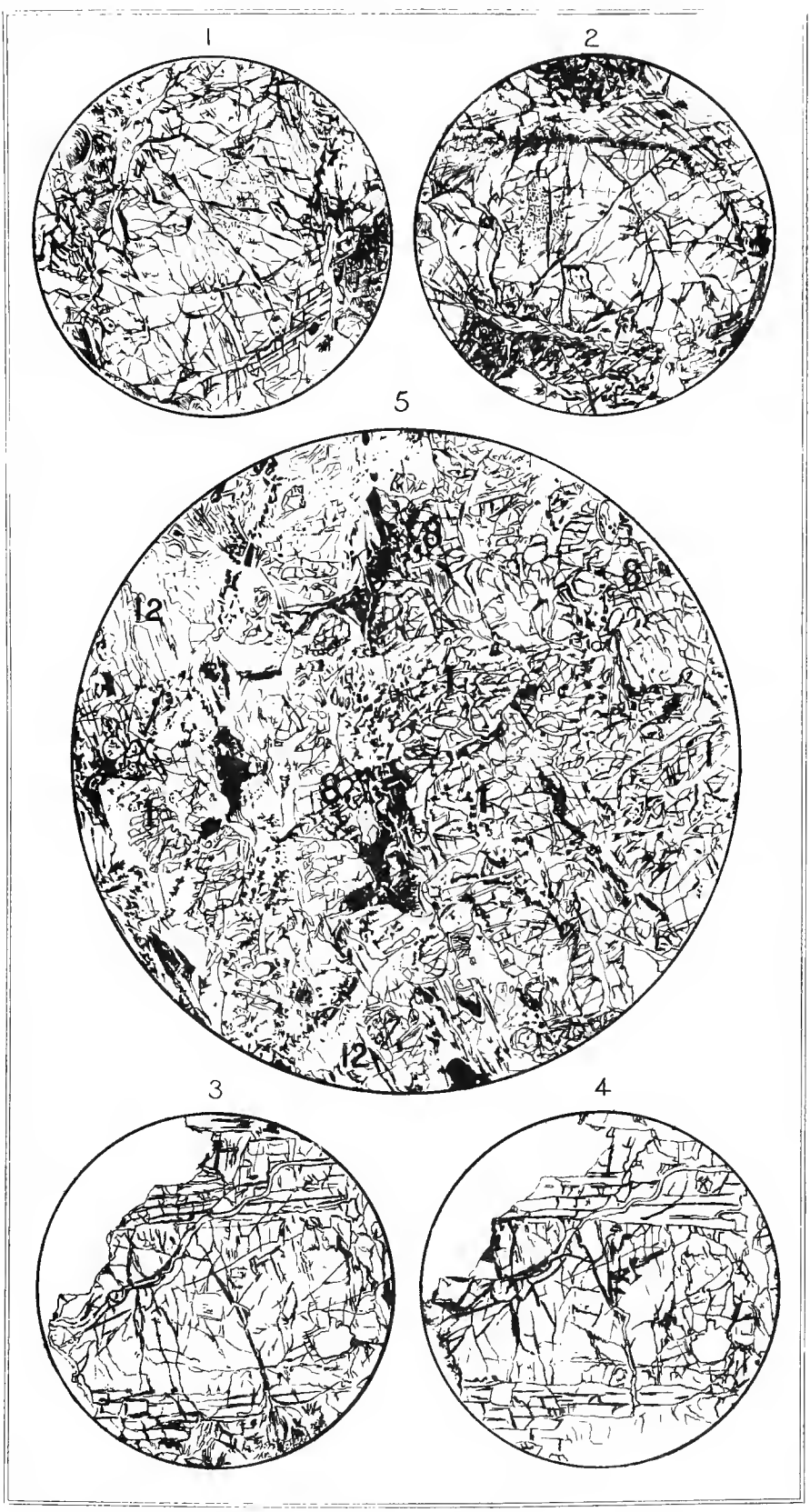


PLATE VII.

FIGS. I., II., III., *and* IV.

AUGITE-PICRITE. INCHCOLM.

These figures illustrate some of the characters presented by the augite and hornblende of this rock.

Figs. I. and II. show a section of augite with peripheral hornblende. It is taken out of the zone 100 : 001 and shows an optic axis when examined with convergent polarised light. Fig. I. is drawn with the short diameter of the polarising nicol (analyzer removed) parallel with the length of the crystal-section; Fig. II. with the short axis at right angles to the length of the crystal-section. The augite is seen to be markedly pleochroic. It must be remembered, however, that as the section is approximately at right angles to an optic axis it is not cut in such a direction as to contain two of the axes of elasticity. The central portion of the augite is nearly colourless and the colour of the external portion increases somewhat towards the margin. The hornblende is remarkable on account of the intensity of its pleochroism. The boundary between the augite and hornblende is often very irregular: flecks and irregular patches of the latter mineral penetrate into the former near the zone of contact.

Figs. III. and IV. are taken from a section parallel to the vertical axis of both crystals. They show the "hour-glass" structure of the augite. Fig. III. is drawn with the polariser only, the short diameter of the nicol being parallel with the vertical axis of the crystal. Fig. IV is drawn with polarised light; the nicols being arranged in such a way as to bring out strongly the "hour-glass" structure.

The interior and colourless portion of the augite extinguishes at an angle of 39°; the external and coloured portion at an angle of 47°. The section is therefore taken approximately parallel to the clinopinacoid (010).

FIG. V.

HORNBLENDE-PICRITE.

PENARFYNYDD, ANGLESEA.

Magnified 25 diameters. Drawn with polariser only; short diameter of nicol right and left.

The minerals represented are olivine (1), hornblende (8), chlorite (12), magnetite and serpentine.

The olivine is colourless. It contains inclusions of magnetite and is traversed by narrow anastomosing strings of serpentine. The hornblende is mainly composed of the brown variety, but it contains here and there small colourless patches. It contains also strings and patches of dusty looking magnetite. The chlorite appears to result from the alteration of biotite. Its mode of occurrence and optical characters are described in the text.

This rock was first described by Professor BONNEY (G.M., 1880, p. 208). It is probably intrusive in Lower Arenig strata.

KEY PLATE. 8

FIG. 1

FIG. 2

PLATE VIII.

FIG. I.

HORNBLENDIC DIABASE (TAWNEY). CAREG LLEFAIN, CAERNARVONSHIRE.

Magnified 25 diameters. Drawn with polariser only; short diameter of Nicol right and left.

The minerals represented are hornblende (8), augite (7), felspar (10), magnetite and viridite (13).

The hornblende is the usual brown variety. It occurs in large irregular plates, in which other minerals are frequently enclosed.

The augite is nearly colourless. It is intergrown with, and sometimes enclosed in the hornblende.

The felspar occurs in lath-shaped sections, and also in irregular plates. It is frequently traversed by cracks which have been filled with viridite, as is represented in the lower part of the figure near the margin to the right. The felspar itself is often perfectly unaltered, and shows lamellar twinning. In the upper part of the figure (10A) there is a cloudy patch giving aggregate polarisation which probably represents an alteration product after felspar.

Viridite is not used as the name of a definite mineral species; but only for those green alteration products which cannot be definitely referred either to chlorite or serpentine. Some of the viridite in the slide from which the figure is taken certainly arises from the alteration of hornblende; but the portions represented in the figure are suggestive of olivine.

The rock forms a part of the Penarfynydd ridge, and is apparently intrusive in Lower Arenig strata. It has been described by Mr. TAWNEY (G.M., 1880, p. 211).

FIG. II.

JUNCTION OF TROKTOLITE AND SERPENTINE, COVERACK COVE, CORNWALL.

Magnified 25 diameters. Ordinary light.

The minerals represented are olivine (1), plagioclase (10), iron-oxides and serpentine.

The section is cut so as to show the junction between the troktolite (anorthite-olivine rock) and serpentine. The troktolite is intrusive in the serpentine according to Professor BONNEY.

The right-hand third of the figure represents the serpentine; the left-hand two-thirds, the troktolite. The serpentine has been formed by the alteration of an olivine rock, and grains of unaltered olivine still remain. It has been stained along the cracks by the separation of ferric oxide.

The olivine of the troktolite has been changed into a precisely similar serpentine.

The plagioclase of the troktolite, though much traversed by cracks, is remarkably fresh. It occurs in large irregular grains and coarse granular aggregates. The individuals frequently show, under crossed nicols, a broad lamellar twinning.

In other portions of the slide the cracks in the felspars are seen to radiate from the altered olivines, as though they had been formed by mechanical forces due to an expansion of the olivine consequent on serpentinisation. The twin lamellæ of the felspar are often bent; a fact which also proves that the crystals have been strained.

The rock has been described by Professor BONNEY (Q.J.G.S., vol. XXXIII., p. 906; also G.M., 1885, p. 442).

KEY PLATE. 9

FIG. 1

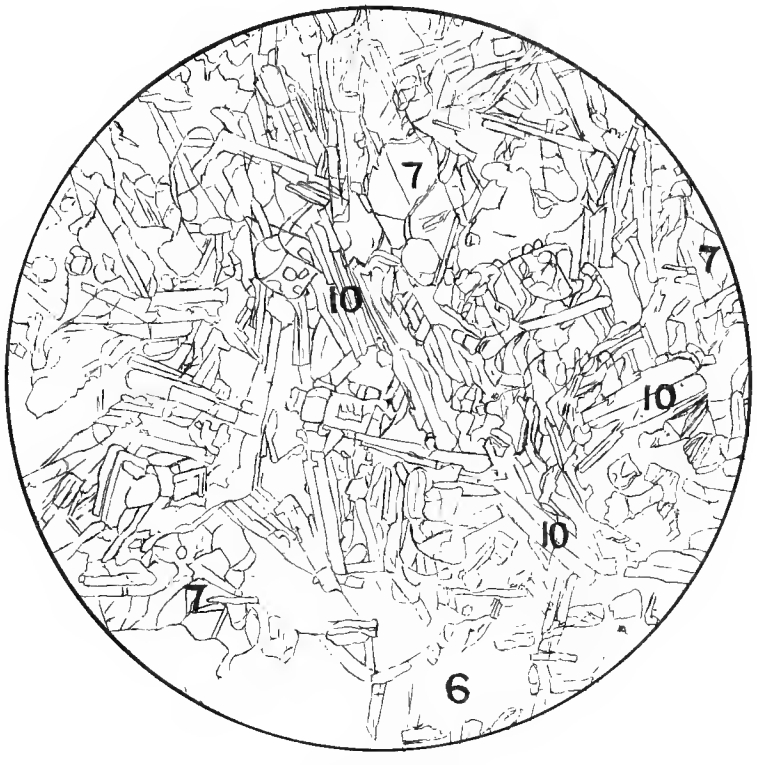


FIG. 2

PLATE IX.

FIG. I.

OLIVINE-DOLERITE.

TIDESWELL DALE, DERBYSHIRE.

Magnified 50 diameters. Nicols crossed.

This figure shows plagioclase (10), augite (7), and dark pseudomorphs after olivine (6).

The sections of augite are large irregular plates. Olivine-pseudomorphs and felspar occur as inclusions. The large patch of augite in the upper part of the figure gives the yellowish-green of the second order. Other portions of augite in the same figure are cut nearly at right angles to an optic axis, and give only the pale neutral tints of the first order.

The plagioclase, probably labradorite, occurs in lath-shaped sections, and shows the usual twining on the albite plan. It invariably polarises in the neutral tints of the first order.

No fresh olivine occurs in the slide, but green serpentinous pseudomorphs, often rendered almost opaque by iron oxide, are abundant. The rock is associated with carboniferous limestone. It was originally identical in structure and composition with the Tertiary olivine-dolerites of the West of Scotland (see plate X.).

FIG. II.

OLIVINE-DOLERITE.

TIDESWELL DALE, DERBYSHIRE.

Magnified 50 diameters. Ordinary light.

The minerals represented are olivine (1), plagioclase (10), augite (7), magnetite, and serpentine after olivine.

Olivine occurs in large crystals and grains. The alteration of the olivine at the margins and along cracks is well seen in the large central crystal.

The felspar occurs in lath-shaped sections.

Augite occurs only in the form of granules between the lath-shaped felspar sections.

The rock is similar to the preceding one in composition, but differs from it in micro-structure. Fig. I. illustrates the ophitic type of dolerite; Fig. II. the type with granular augite.

KEY PLATE 10

FIG. 1

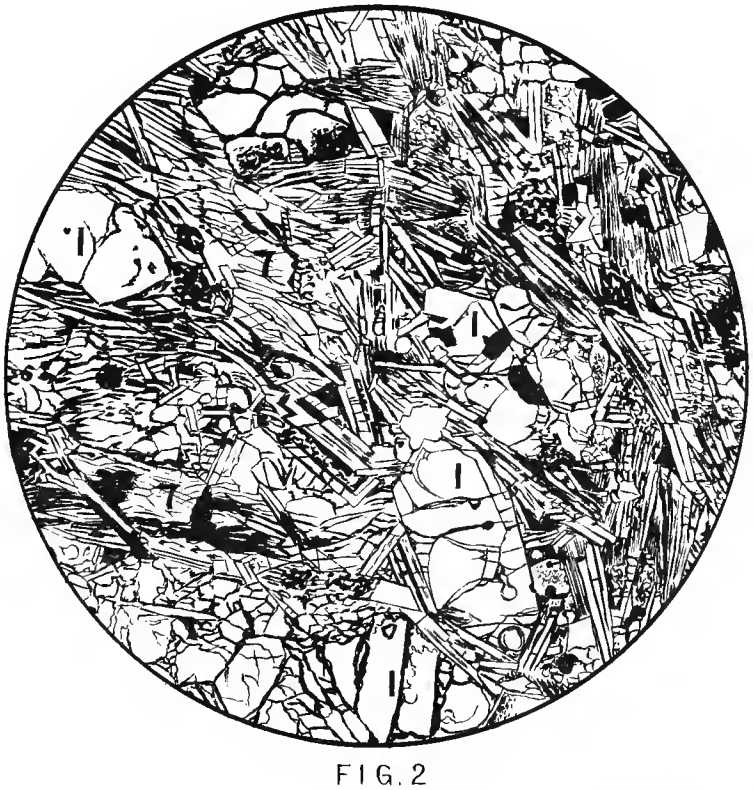


FIG. 2

PLATE X.

FIG. I.

OLIVINE-DOLERITE.

TOBERMORY, MULL.

Magnified 50 diameters. Ordinary light.

This figure shows augite (7), olivine (1), plagioclase (10), and magnetite.

Olivine occurs in more or less irregular grains, and is sometimes included in the augite.

The augite occurs in large ophitic plates.

The felspar occurs in lath-shaped sections which frequently penetrate and are sometimes completely enclosed in the augite. It is often rendered more or less cloudy by alteration

Magnetite occurs in crystals and grains.

The rock is one of the Tertiary dolerites of Scotland. It is identical in structure and composition with the Carboniferous dolerite of Tideswell Dale, in Derbyshire, and closely resembles many of the altered dolerites (diabases) associated with the Lower Palæozoic rocks of Wales. The last-mentioned rocks are, however, as a general rule more altered, and olivine appears in many cases to have been absent.

FIG. II.

OLIVINE-DOLERITE.

PORTREE, SKYE.

Magnified 50 diameters. Crossed nicols.

This figure shows the same constituents as the preceding.

The olivine sometimes occurs as fairly well marked crystals. The two crystals near the centre of the figure give the red of the first order; whereas the augite in the same portion of the slide gives only the neutral tints of the same order.

The portion of the slide here figured illustrates the transition from the ophitic type of texture to that characterised by granular augite. The somewhat parallel arrangement of the plagioclase crystals, seen in a certain portion of the figure, has evidently been determined by differential movement in the mass. In these portions the ophitic plates have been broken up into granules.

In the left-hand portion of the figure the ophitic character of the augite is still preserved, and in other portions of the same slide the rock is a normal ophitic olivine-dolerite.

The association of the two types of texture in the same rock-mass may be observed also in the Carboniferous olivine-dolerite of Tideswell Dale.

KEY PLATE II.

FIG 1

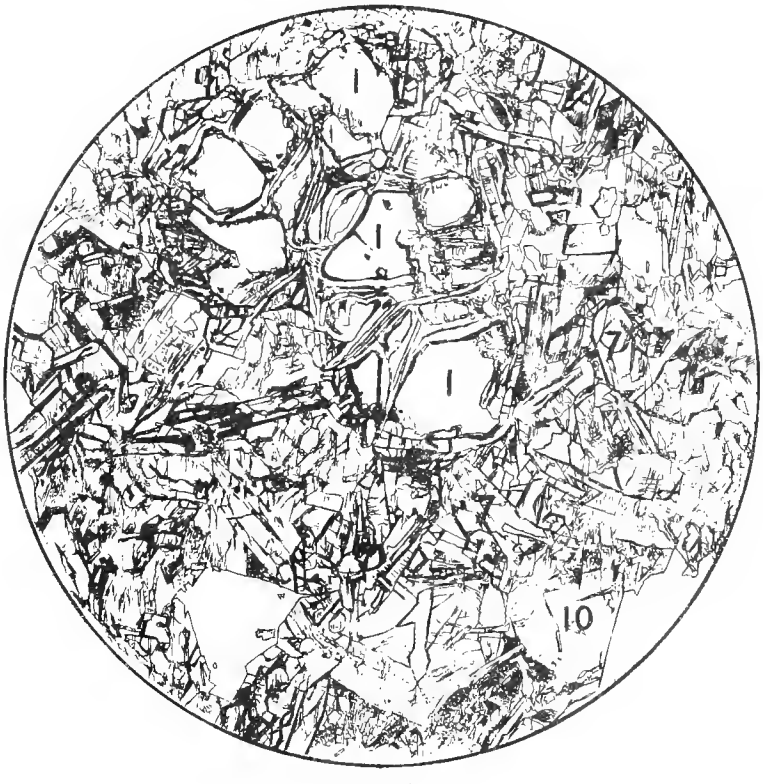


FIG 2.

PLATE XI

FIG. I

DIABASE.

SIDE OF CLOCHNANT : $1\frac{1}{2}$ m. E.S.E. OF BLAENYDRE.

Magnified 25 Diameters. Ordinary light.

The minerals represented are augite (7), hornblende (8), magnetite or ilmenite, serpentine (6) and pseudomorphs after felspar (10a).

The augite is present in large ophitic plates. Hornblende occurs sparingly and appears to be intergrown with the augite. The serpentine is yellow and similar to that which commonly results from the alteration of olivine, except that secondary iron-oxides are rare.

The felspar is mostly represented by a turbid substance giving aggregate polarisation. Sometimes traces of twin lamellation may be detected.

The rock was originally an ophitic dolerite. It is associated with strata of Lower Bala age. (See Q.J.G.S., vol. XXXVI. p. 279).

FIG. II.

OLIVINE-DOLERITE.

ROWLEY HILLS, STAFFORDSHIRE.

Magnified 50 Diameters. Ordinary light.

The minerals represented are olivine (1), augite (7), felspar (10), iron-ores and serpentine. Colourless needles of apatite and a small amount of isotropic interstitial matter also occur.

The large olivine in the upper part of the figure is not an individual, but an aggregate of seven or eight grains. Serpentinisation has taken place along the boundaries of the different grains and in one or two cases along cracks traversing individual grains. The olivine is distinctly coloured, even in very thin sections, and as the colour approximates to that of hyalosiderite and fayalite it seems reasonable to infer that it is rich in iron.

Augite occurs in small crystals, grains and granular aggregates : not in large ophitic plates. It is brown in colour.

Felspar plays the rôle of groundmass in the rock and occurs in forms giving lath-shaped sections and also in more or less irregular grains or plates.

A small quantity of glassy or micro-felsitic matter occurs here and there in the interstices between the felspars.

The rock is associated with Carboniferous strata. It has been described by Mr. ALLPORT (Q.J.G.S., vol. XXX., p. 548).

KEY PLATE 12

FIG 1.

FIG. 2.

PLATE XII.

DOLERITE.

TYNEMOUTH, NORTHUMBERLAND.

Magnified 25 diameters. Fig. I., ordinary light; Fig. II., with crossed nicols.

The substances represented are plagioclase (10), augite (7), magnetite, serpentine (6) and interstitial matter.

The felspars of this rock belong to two periods of consolidation. They consist of (*a*) porphyritic crystals and crystalline granular aggregates, and (*b*) crystals of the groundmass giving lath-shaped sections.

The porphyritic felspars, one of which is represented in the upper part of the figure, are allied to anorthite in composition and optical characters (see Q.J.G.S., 1884, p. 234). They contain solid inclusions and often show a zonal structure.

The felspars of the groundmass usually show binary or multiple twinning. They are probably labradorite.

The augite is nearly colourless in thin sections. It occurs in grains and granular aggregates. The opaque iron-ores are almost, if not entirely, limited to the interstitial matter. They occur as rods and granules.

As a rule serpentine is absent from this rock. One dark patch, probably representing olivine, occurs in the figure somewhat to the right of the centre.

The interstitial matter is crowded with rods and granules of opaque iron-ore, ill-defined brownish granular matter and microlites of felspar. A considerable portion of it is seen, in very thin sections, to be isotropic, but as it does not appear absolutely structureless it must be referred to the micro-felsite of ROSENBUSCH.

The rock forms a dyke in Carboniferous strata. The date of intrusion cannot, however, be determined with precision.

KEY PLATE 13

FIG. 1

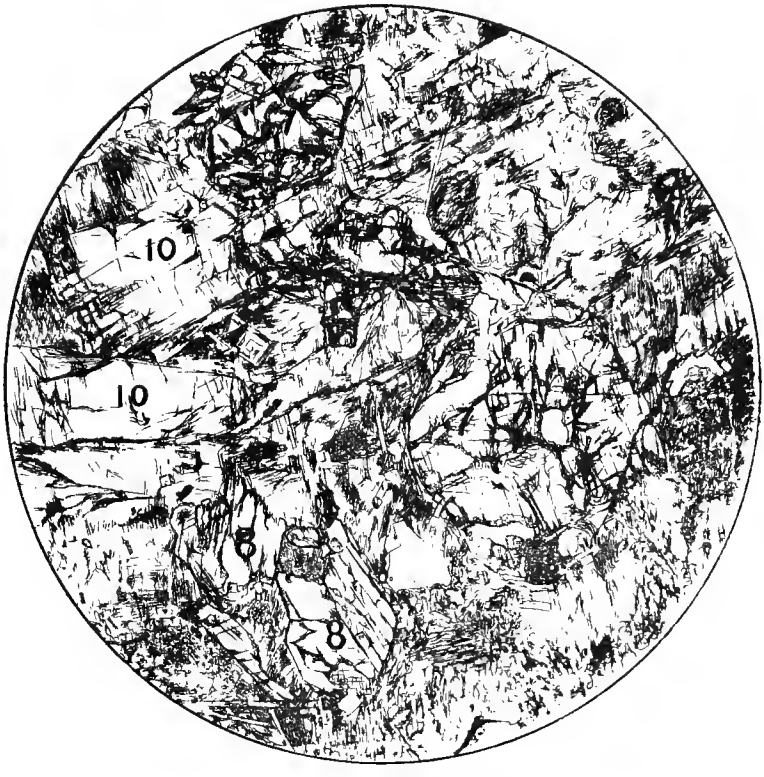


FIG. 2

PLATE XIII.

FIG. I.

FELSPAR-AUGITE-HORNBLENDE ROCK,

FORMING A VEIN IN MICACEOUS DOLERITE.

DENISTON HILL, GLASGOW.

Magnified 50 diameters. Ordinary light.

This figure shows felspar (10), augite (7), hornblende (8) and magnetite. The felspar gives broad lath-shaped sections and is more or less changed to a brown granular decomposition product. The augite exhibits a pale violet tint, and occurs in fairly well-formed crystals. It is changed to chlorite along the margins in places. It occurs as inclusions in the felspar and was evidently formed before the latter mineral.

The hornblende is the deep brown "basaltic" variety, sometimes known as basaltine. It occurs in well-formed crystals in other portions of the slide, and shows the characteristic pleochroism (a, yellowish brown; β and γ a rich clove brown). This rock has been described by Mr. ALLPORT (Q.J.G.S., Vol. XXX, p. 561).

FIG. II.

ENSTATITE-DOLERITE.

PORTION OF THE WHIN SILL, MIDDLETON.

Magnified 50 diameters. Ordinary light.

The minerals represented are augite (7), plagioclase (10), enstatite (2), mica (9), and magnetite or ilmenite.

The augite is nearly colourless. It occurs in the form of irregular grains and granular aggregates. The felspars penetrate the augite; but the rock does not show the ophitic texture in any marked degree because the latter mineral does not occur in the form of large irregular plates (compare fig. 1, plate X.)

The felspar occurs in lath-shaped sections which are as a rule rather short in proportion to their length, and also as irregular colourless plates. The analysis of the isolated felspar substance suggests the presence of andesine, or at any rate a felspar of more acid composition than labradorite.

In the upper part of the figure is a longitudinal section of a colourless rhombic pyroxene (enstatite). It gives the characteristic low tint between crossed nicols, and extinguishes parallel to the length of the section. The alteration of this mineral to a green fibrous substance (bastite) having the axes of the fibres parallel with the vertical axis of the original mineral is highly characteristic of the rhombic pyroxenes.

Two irregular flakes of a brown mica are represented in the figure. The only other mineral in addition to the magnetite or ilmenite which requires notice is the one occurring in long colourless acicular microlites. This is probably apatite.

KEY PLATE 14.

FIG. 1

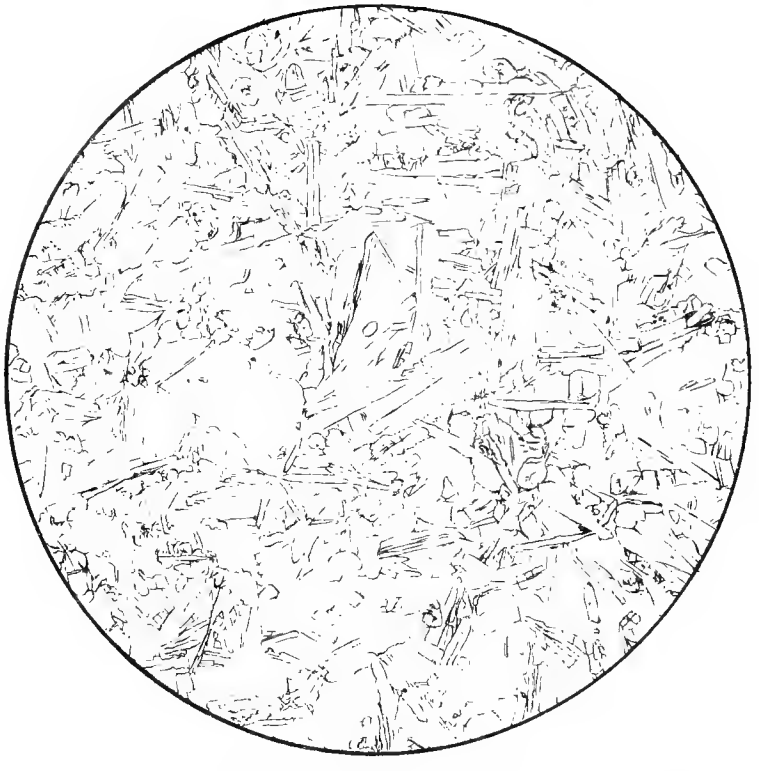


FIG. 2.

PLATE XIV.

FELSPAR-AUGITE ROCK.

SOUTH DYKE IN SHANKHOUSE PIT, NORTHUMBERLAND.

Magnified 50 diameters. Fig. I. ordinary light; fig. II. with crossed nicols.

The substances represented are plagioclase (10), augite (7), magnetite and interstitial matter.

The felspar occurs in elongated lath-shaped sections, often showing ragged terminations. The individuals are usually twinned. An examination of fig. II. will show that the felspar must have crystallised before the augite.

The augite is nearly colourless in thin section. It occurs in irregular grains, sometimes showing a tendency to elongation in one direction.

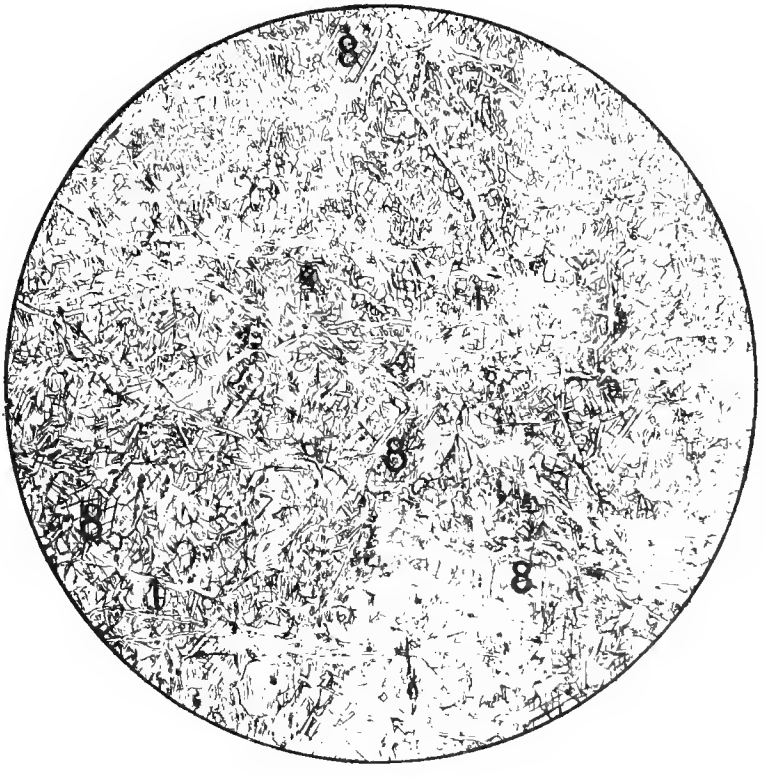
The magnetite is wholly present in the interstitial matter where it occurs as minute crystals and rods.

When the interstitial matter is examined with a high power it is seen to consist of a base of perfectly colourless isotropic glass (the acid residuum of the magma,) in which innumerable minute spherical bodies (globulites) and crystals and rods of magnetite are scattered.

The yellowish brown patches seen in fig. I. appear to represent portions of the interstitial matter which have been more or less altered. The dyke is intrusive in the coal measures of the district. Its precise age is unknown.

KEY PLATE 15

FIG 1



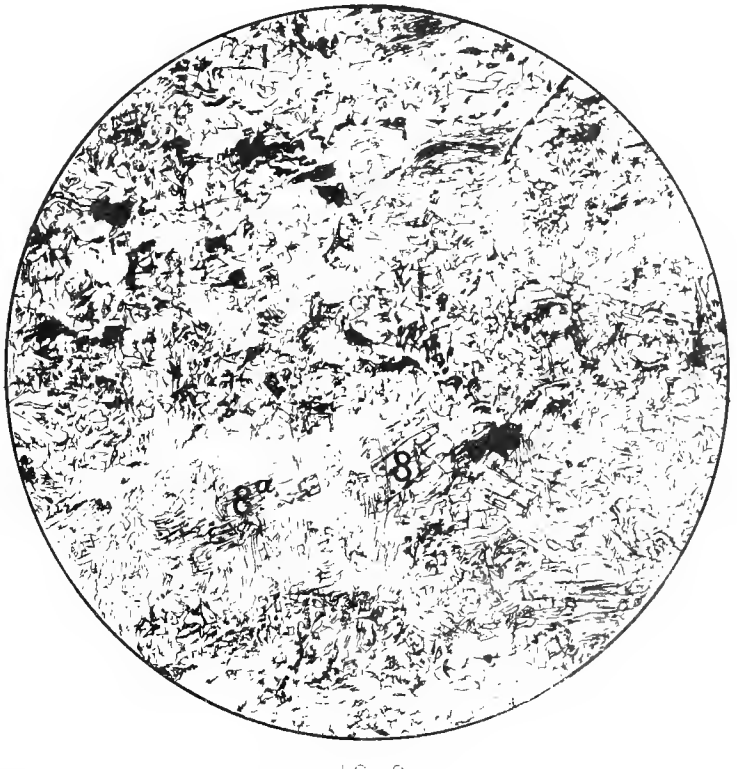


FIG 2

PLATE XV.

FIG. I.

OLIVINE-HORNBLENDE SERPENTINE.

KYNANCE, THE LIZARD, CORNWALL.

Magnified 25 diameters. Ordinary light.

The substances represented in this figure are olivine (1), hornblende (8) and serpentine stained with ferric oxide.

The olivine is traversed by the usual network of serpentine veins, portions of the unaltered mineral remaining as minute granules in the centres of the meshes. The serpentine substance is stained with ferric oxide. The outlines of the original olivine grains are indicated, under crossed nicols, by the areas over which the detached grains give simultaneous extinction.

The hornblende is pale green in colour and without any definite crystalline form. It is comparatively unaltered, and does not show any marked pleochroism in thin section. The grains are elongated in the direction of the vertical axis, and are arranged in the rock with their long axes roughly parallel to each other. The cleavages are characteristic and the maximum extinction in the prismatic zone (*i.e.* in the zone in which the cleavage cracks are always parallel), is about 20°. The variety of hornblende here represented appears to be identical with that named smaragdite by BRÖGGER in his description of the Almeklovdal peridotites. The original rock must have been an olivine-hornblende peridotite allied to many of the Norwegian peridotites. (See Professor BONNEY, Q.J.G.S., Vol. XXXIX., p. 23.)

FIG. II.

OLIVINE-HORNBLENDE SERPENTINE.

MULLION COVE, CORNWALL.

Magnified 40 diameters. Ordinary light.

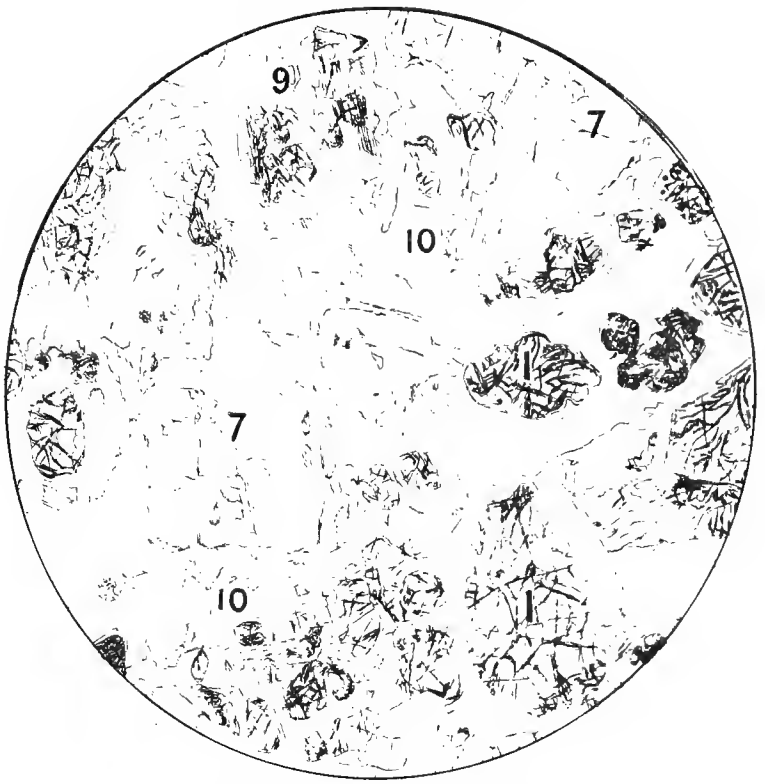
The minerals represented are olivine, hornblende, serpentine and magnetite.

This rock is distinctly banded. The lower portion of the figure represents a band extremely rich in hornblende, the upper portion one extremely rich in olivine. The dividing line runs upward from left to right. The principal interest of the figure lies in the fact that it furnishes evidence of the formation of serpentine from hornblende, as well as olivine. This is well seen near the spot marked 8a. A mass of hornblende is here seen to be broken up at its margins by serpentine veins.

The secondary iron oxides are in the condition of magnetite, and not in the condition of ferric oxide, as was the case in the last described rock.

KEY PLATE 16

FIG. 1



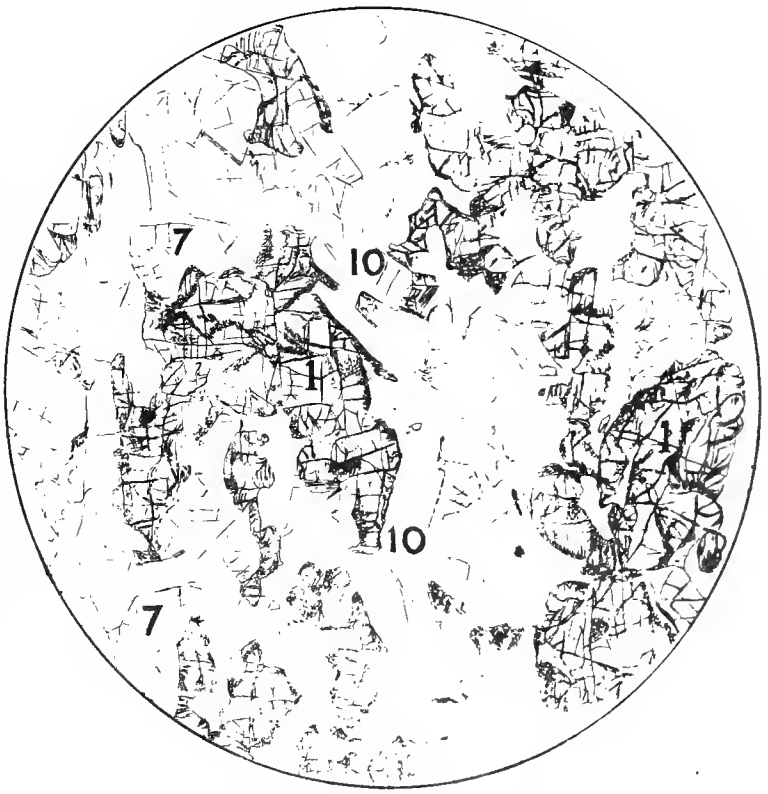


FIG. 2

PLATE XVI.

FIG. I.

PLAGIOCLASE-AUGITE-OLIVINE-MICA ROCK.

BALLACHULISH, SCOTLAND.

Magnified 10 diameters. Ordinary light.

The minerals represented are plagioclase (10), augite (7), olivine (1), mica (9), magnetite and green decomposition products forming a narrow zone round each of the olivines.

The plagioclase occurs in the form of extremely irregular grains and plates, and sometimes also in forms which give lath-shaped sections. The boundaries of the individual plagioclase grains cannot, however, be made out without the use of polarised light.

The augite shows a very pale greenish tinge, which is somewhat exaggerated in the figure for the purpose of distinction. It contains inclusions of the brown mica, and sometimes also of minute magnetite crystals.

The mica is a rich brown variety. It occurs in irregular plates, which are often penetrated by the felspar, and must, therefore, have been formed after the latter mineral.

Olivine occurs in large grains. It appears grey when examined under a low power, in consequence of numerous extremely minute inclusions. When examined with a high power these inclusions are often seen to be aggregated in one or more sets of parallel bands. Thus, in the large grain near the bottom of the figure to the right two sets of bands, intersecting approximately at right angles, may be seen with a high power. The olivine substance itself appears to be perfectly colourless. (See JUDD, Q.J.G.S., 1885, p. 273.) The olivines are also traversed by irregular cracks, along which magnetite has been formed. Each olivine grain when it comes in contact with felspar is surrounded by a narrow fringe of a green substance, giving aggregate polarisation.

The order of separation of minerals in this rock appears to have been magnetite, olivine, felspar, mica and augite. Original magnetite is, however, comparatively rare.

FIG. II.

PLAGIOCLASE-OLIVINE-AUGITE ROCK.

(OLIVINE-GABBRO.)

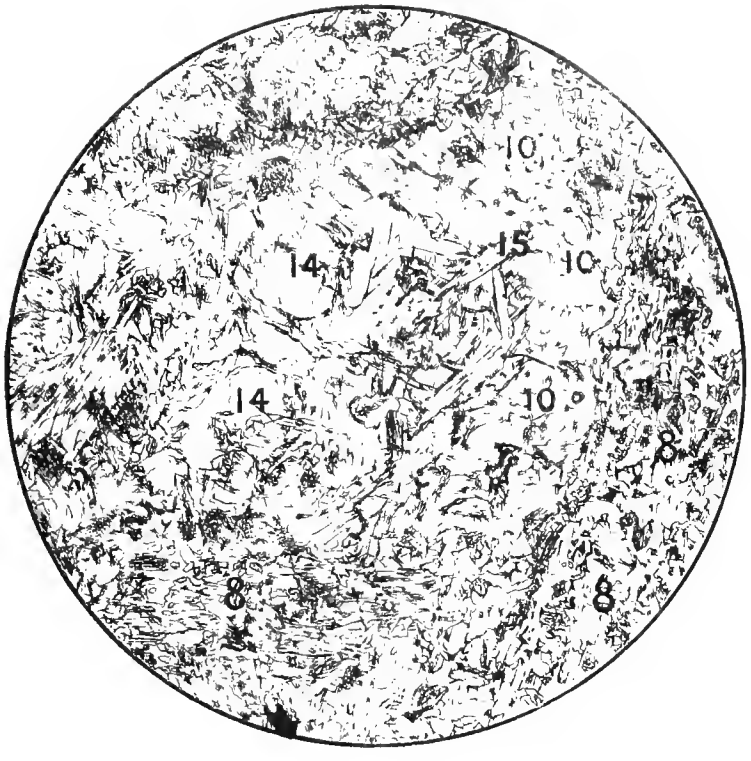
Isle of Mull. Magnified 10 diameters. Ordinary light.

The minerals represented are plagioclase (10), olivine (1), augite (7) and magnetite. The felspar occurs mostly in the form of irregular grains. The augite is the pale green variety. It occurs in small irregular plates which are interfered with by the felspars.

The olivine is extremely abundant, and presents characters which are somewhat similar to those of the same mineral in Fig. I. The minute inclusions are, however, less numerous.

KEY PLATE 17.

FIG 1



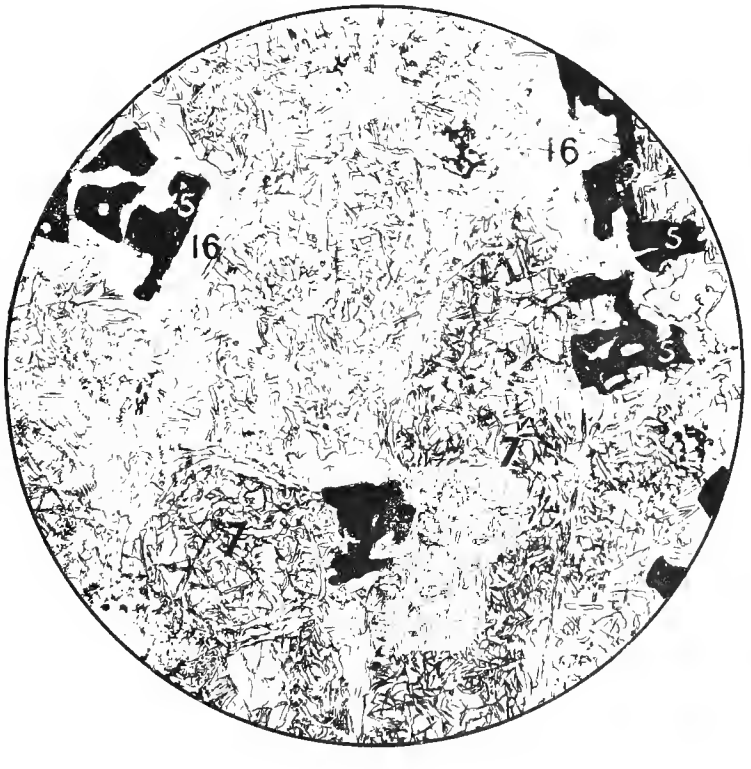


FIG 2.

PLATE XVII.

FIG. I.

PLAGIOCLASE-AUGITE ROCK, NEAR GRANITE.

TOLCARN, NEAR PENZANCE.

Magnified 40 diameters. Ordinary light.

The minerals represented are uralitic and actinolitic hornblende (8), tourmaline (14), secondary magnetite, modified and secondary felspar (10) and apatite (15).

On the right hand side of the figure is a portion of a large patch of fibrous hornblende, in which the axes of the fibres are arranged with a certain amount of parallelism. This is what is indicated by the term uralitic. The term actinolitic is applied to detached needles of hornblende, which may often be observed in the colourless felspar substance. These are not well seen in the figure.

Tourmaline is represented by a group of three individuals, one of which is cut exactly and the other two nearly at right angles to the vertical axis. The three individuals evidently radiate from a common centre. They show a beautiful zonal structure due to the alternation of the blue (indicolite) and brown varieties. The individual occurring to the right is penetrated by a colourless needle, giving straight extinction and possessing the refractive power of apatite. The colourless substance splits up under crossed nicols into irregular portions of considerable size, which extinguish simultaneously. This is doubtless felspar, but that it is largely of secondary origin appears to be proved by the fact that it contains needles of actinolitic hornblende. The magnetite in the portion represented appears to be mostly of secondary origin and to be associated with the uralitic hornblende.

FIG. II.

ANOTHER VARIETY OF THE SAME ROCK.

Magnified 25 diameters.

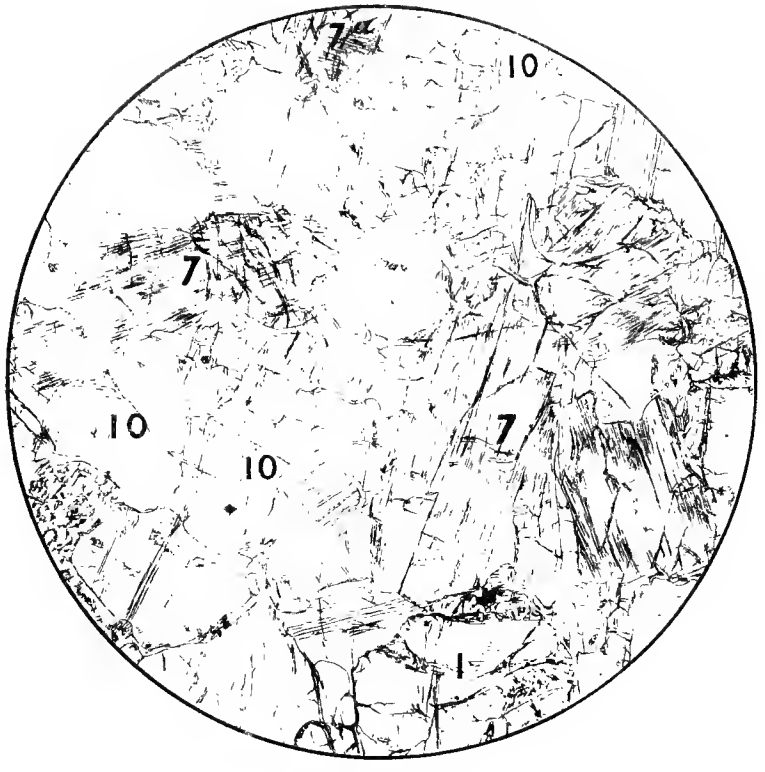
This figure shows augite (7), uralitic and actinolitic hornblende, brown mica (16), felspar, and ragged plates of titaniferous iron ore (5) partially changed to leucoxene. The augite is a pale pinkish variety. It is changed at the margins and along cracks into uralitic and actinolitic hornblende.

The brown mica occurs in the form of minute overlapping scales, which cannot be resolved into distinct individuals with the magnifying power employed. It is the mineral which is so highly characteristic of contact alteration by granite, and which occurs both in the altered sediments and in the altered eruptive rocks of Cornwall, the Harz and other localities. The felspar substance occurs as a rule in large irregular plates, without twinning ; sometimes, however, it occurs as minute granular aggregates (felspar-mosaic). That it is of secondary origin at any rate in its present form appears proved by the occurrence in it of inclusions of actinolitic hornblende and brown mica ; both secondary minerals in this rock.

The rocks represented in this plate were first described by Mr. ALLPORT.—(Q.J.G.S., Vol. XXXII., 1876, p. 418).

KEY PLATE 18

FIG 1



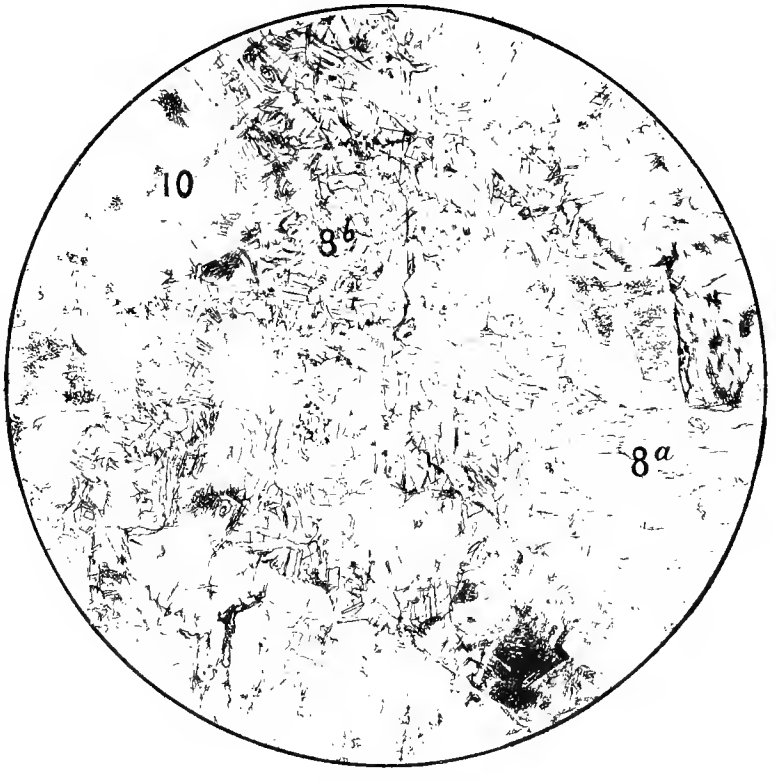


FIG 2

PLATE XVIII.

FIG. I.

PLAGIOCLASE-AUGITE-OLIVINE ROCK. GRANITIC TEXTURE.

OLIVINE-GABBRO. LOCH CORUISK, SKYE.

Magnified 35 diameters. The felspar is represented with crossed nicols : the augite and olivine are drawn with ordinary light.

The minerals represented are plagioclase (10), augite and diallage (7) and olivine (1).

The felspar occurs in the form of grains and aggregates of such grains. It shows twinning on the albite and sometimes also on the pericline type.

The pyroxene is partly in the condition of augite, and partly in that of diallage. The two conditions are often illustrated in one and the same crystalline individual. The fine striation indicative of diallage is due to the presence of minute rod-like or tabular inclusions, arranged in planes parallel or approximately to the orthopinacoid. This can be determined by an observation on the section of which a small portion only (7a) is included within the field view at the top. This section shows three well marked cleavages in addition to the plane of easy separation marked out by the inclusions. Two of these are the prismatic cleavages, for they intersect at right angles, and the section shows in convergent polarised light an optic axis on the margin of the field of view. The optic axial plane (010) lies parallel with the third cleavage, and at right angles to the plane in which the inclusions lie, which is thus determined to be the orthopinacoid (100).

The olivine is traversed by cracks, along which iron oxides have been formed.

The section from which this figure is taken is thicker than usual, so that the felspar gives chromatic polarisation.

FIG. II.

HORNBLENDIC GABBRO.

CROUSA DOWN, NEAR COVERACK, CORNWALL.

Magnified 40 diameters.

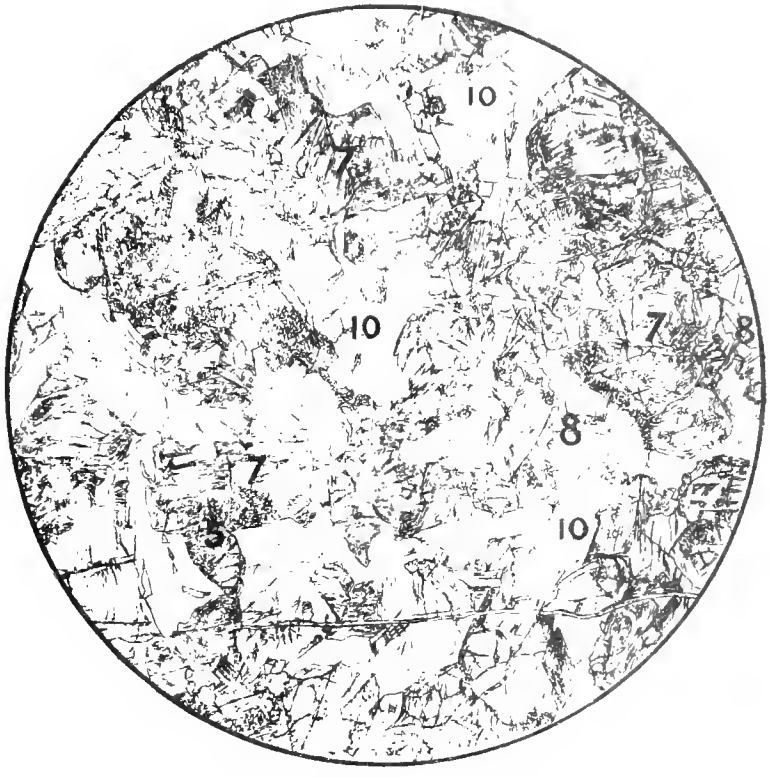
The minerals represented are uralitic (8a) and actinolitic hornblende (8b) and plagioclase (10).

The uralitic portion of the hornblende is fibrous, but the axes of the fibres are not rigidly parallel with each other. The central portion of the figure is occupied by a confused aggregate of fibres and grains, giving vivid chromatic polarisation under crossed nicols. At the margin of this portion is a fringe of actinolitic hornblende. The pleochroism of this hornblende is as follows : α = pale green, β = pale brown or brownish green, γ = bluish green. The felspar which may be determined by observations on cleavage flakes to be labradorite is very fresh. It frequently shows twinning lamellæ under crossed nicols, and the lamellæ are often bent. The crystals are sometimes cracked. Here and there the felspar contains cloudy brownish patches. The actinolitic fringe projects into the felspar substance, and detached needles of actinolite occur abundantly as inclusions in the felspar.

In other portions of the slide diallage may be seen partially metamorphosed to uralite and actinolite.

KEY PLATE 19

FIG 1



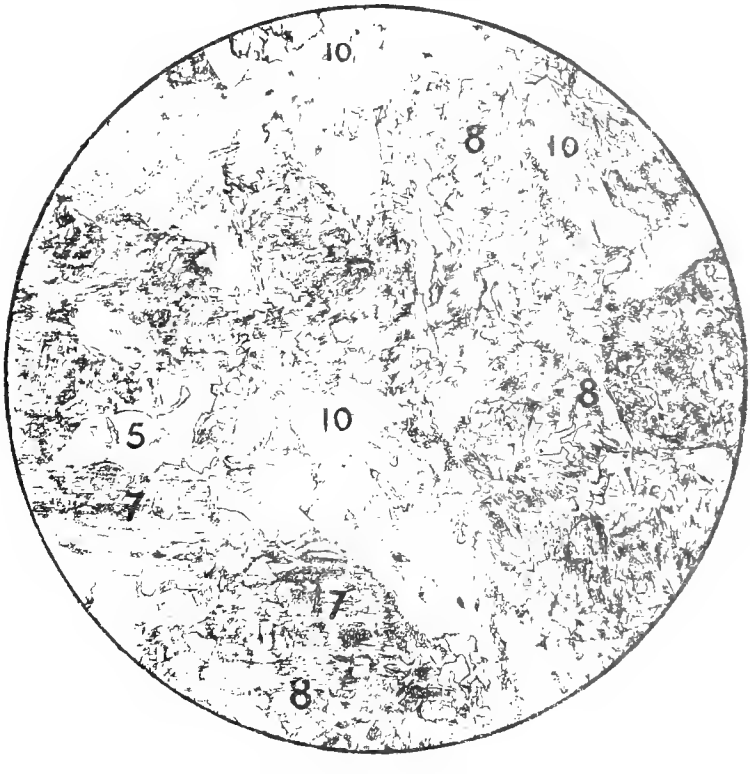


FIG. 2

PLATE XIX.

FIG. I.

PLAGIOCLASE-PYROXENE ROCK.

DYKE, NEAR SCOURIE, SUTHERLANDSHIRE.

Magnified 25 diameters. Ordinary light

The figures in this and the next plate are intended to illustrate different stages in the metamorphism of a basic igneous rock. The minerals represented are plagioclase (10), pyroxene (7), titaniferous iron ore (5), and hornblende (8).

The plagioclase is, as a rule, somewhat cloudy, owing to the presence of excessively minute inclusions. It gives broad lath-shaped sections which sometimes penetrate the pyroxene, thus showing that the rock approaches the ophitic dolerites in structure.

The pyroxene is not deeply coloured. It occurs in grains and irregular plates. In some places it is free from inclusions, and shows only the prismatic cleavages ; in other places it is rendered cloudy by minute inclusions in the form of dots, rods or plates. Where the minute dots alone occur they are generally distributed irregularly through the crystal-substance, giving rise to cloudy patches or zones. Where the rods or plates occur we have the structure of diallage or pseudo-hypersthene (see page 29).

The titaniferous iron-ore appears in the section in the form of irregular plates. Green secondary hornblende is very sparingly represented in this section.

The microstructure of this rock is essentially that of an igneous product. This is shown by the form of the felspar, and by its relation to the pyroxene. Whether the rock should be called a dolerite or a gabbro is a matter of little importance. The structure (ophitic or sub-ophitic) is that of a dolerite, but the occasional occurrence of diallage serves to link the rock with the gabbros.

The rocks represented in this and the next plate were taken from a dyke in the Hebridean gneissic system of Sutherlandshire. They are different portions of one and the same rock-mass.

FIG. II.

PLAGIOCLASE-PYROXENE-HORNBLENDE ROCK.

(PROTEROBASE).

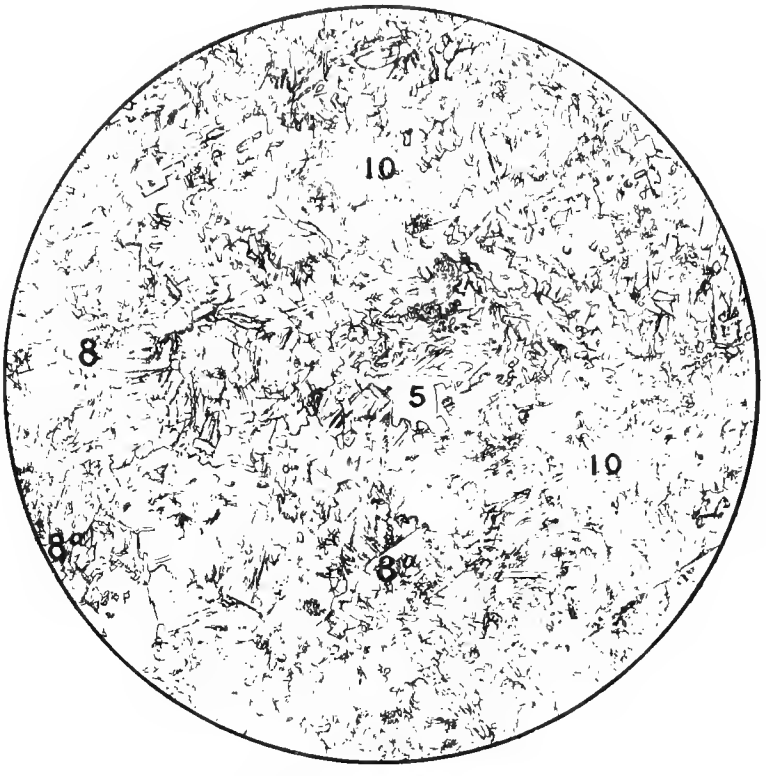
Portion of same rock-mass as Fig. I.

Magnified 25 diameters. Ordinary light.

The constituents are the same as in the preceding figure. The secondary hornblende is present in much greater quantity, and the pyroxene in proportionately smaller quantity. The plagioclase is partly cloudy and partly colourless. The lath-shaped form of the sections is less pronounced than in Fig. I. The cloudy portions often preserve more or less the forms of the original felspars. Under crossed nicols they often give evidence of considerable mechanical deformation. The green hornblende has been especially developed round the margins of the pyroxene. The two most important points illustrated in this figure are :—(1) the increase in the hornblende relatively to the pyroxene, and (2) the partial obliteration of the original microstructure.

KEY PLATE 20.

FIG 1.



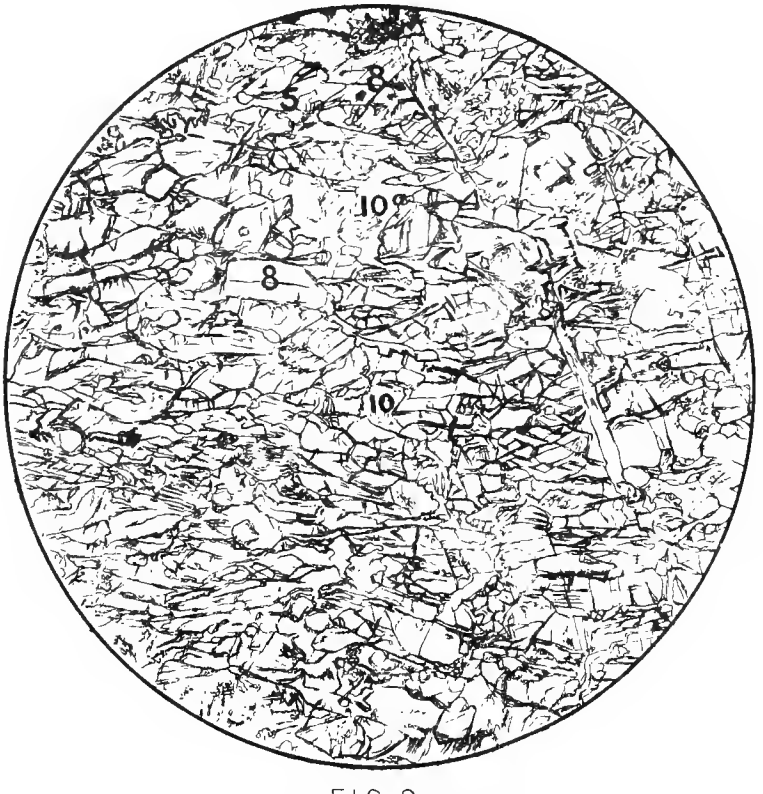


FIG 2.

PLATE XX.

FIG. I.

PLAGIOCLASE-HORNBLENDE ROCK.

(EPIDIORITE.)

PORTION OF SCOURIE DYKE.

Magnified 25 diameters. Ordinary light.

The minerals represented are plagioclase (10), hornblende (8), and titaniferous iron ore (5).

The plagioclase is perfectly colourless and occurs as aggregates of irregular grains, which are in many cases entirely destitute of lamellar twinning. That the original plagioclase has undergone complete molecular reconstruction is proved by the absence of the characteristic lath-shaped sections, by the colourless character of the secondary felspar, and by the occurrence of hornblende-needles as inclusions in the felspar. The original pyroxene in this rock has been replaced by green hornblende.

The hornblende occurs as irregular and often extremely ragged grains. These sometimes contain inclusions of a colourless mineral, presumably quartz (8a). It also occurs in the needle-like form (actinolite), and in this condition is found scattered through the secondary aggregates of felspar.

The micro-structure is entirely different from that represented in plate XIX., Fig. I. The boundaries of the hornblende and plagioclase are not the same as those of the original pyroxene and plagioclase. The molecular rearrangement has been accompanied by the complete obliteration of the micro-structure of the original rock. Plagioclase-hornblende rocks of the type represented in this figure (epidiorites) are extremely common in certain districts. We have no evidence at present to show that they can be produced in any other way than by the metamorphosis of plagioclase-pyroxene rocks. Compare the micro-structure of this rock with that of the Crousa Down Gabbros. (Plate XVIII., Fig. 2).

FIG. II.

HORNBLENDE SCHIST.

FOLIATED PORTION OF SCOURIE DYKE.

Magnified 50 diameters. Ordinary light.

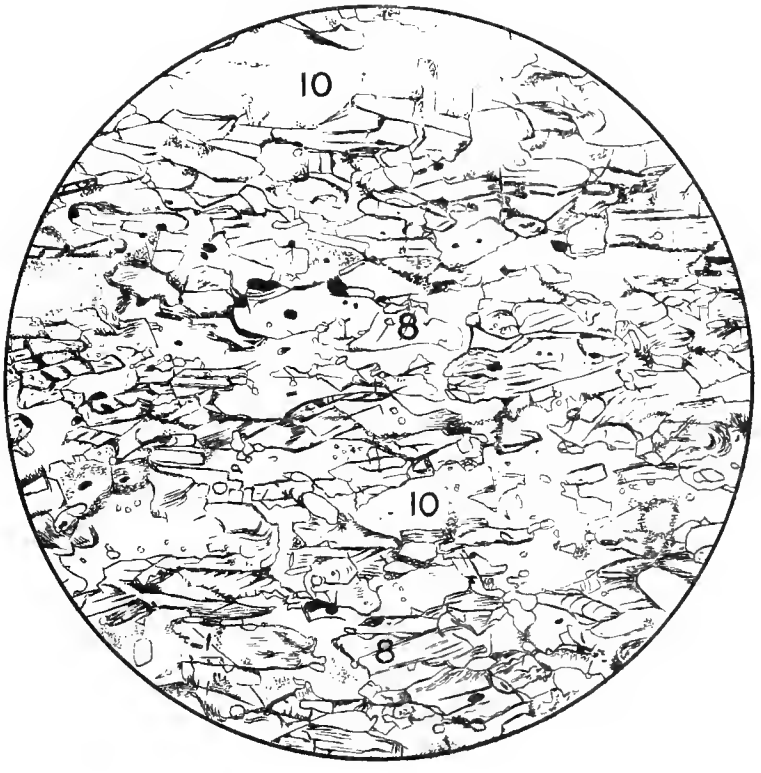
The minerals represented in this figure are the same as those in the last. They are now arranged, however, in parallel bands. The colourless mineral is certainly in most if not in all cases secondary felspar. The cloudy patches (10a) may represent portions of the original felspar which have not undergone reconstruction.

The titaniferous iron ore is arranged in lines parallel with the schistosity and is generally associated with granules of sphene. The hornblende shows a rough kind of orientation which is best seen by rotating the section over the polarizer. Most of the grains appear a deep green when the short axis of the polarizer is parallel with the plane of schistosity, and a pale yellowish green when it is at right angles to this plane.

It will be observed that the micro-structure of the original igneous rock is here replaced by that of a crystalline schist.

KEY PLATE 21.

FIG. 1.



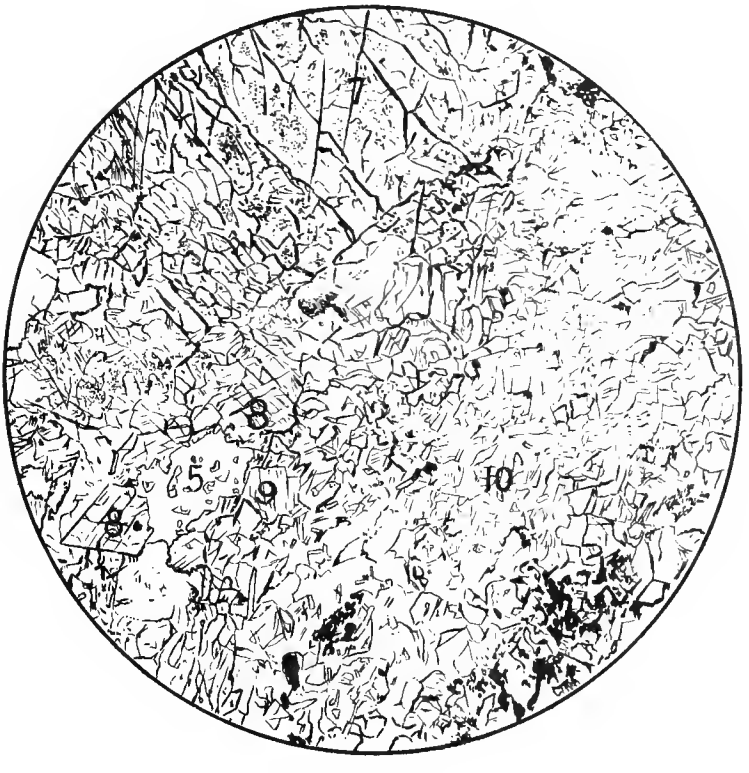


FIG. 2.

PLATE XXI.

FIG. 1.

HORNBLENDE-SCHIST.

MARGIN OF SCOURIE DYKE.

Magnified 100 diameters. Polariser only; short axis N. & S.

The minerals represented are hornblende (8), felspar (10), and iron-ore (5).

This rock was taken from the margin of the dyke and is of finer grain than that taken from the centre. The structure is that of a typical crystalline schist. The felspar is colourless, and occurs in irregular grains. It is for the most part untwinned. Some quartz may be associated with it, but most of those grains which are cut in a direction favourable for examination with convergent light give the figure of a biaxial crystal.

This figure completes the series illustrating the passage of a massive plagioclase-pyroxene rock into a typical hornblende-schist.

FIG. 2.

DOLERITE NEAR CONTACT WITH GRANITE.

NEAR BOVEY TRACEY, DEVONSHIRE.

Magnified 50 diameters.

The minerals represented are augite (7), hornblende (8), brown mica (9), felspar-mosaic (10) and opaque iron ores.

The felspar-mosaic was drawn under crossed nicols. The other constituents are represented as they appear in ordinary light.

The upper portion of the figure shows a somewhat altered crystal of augite with traces of the original prismatic cleavage. This has been altered at its margin into hornblende. The original felspar is now represented by an aggregate of colourless grains. That this aggregate is secondary is proved by the fact that it contains needles and grains of the secondary hornblende. The brown mica belongs to the variety which is characteristic of contact alteration.

KEY PLATE. 22.

FIG. 1

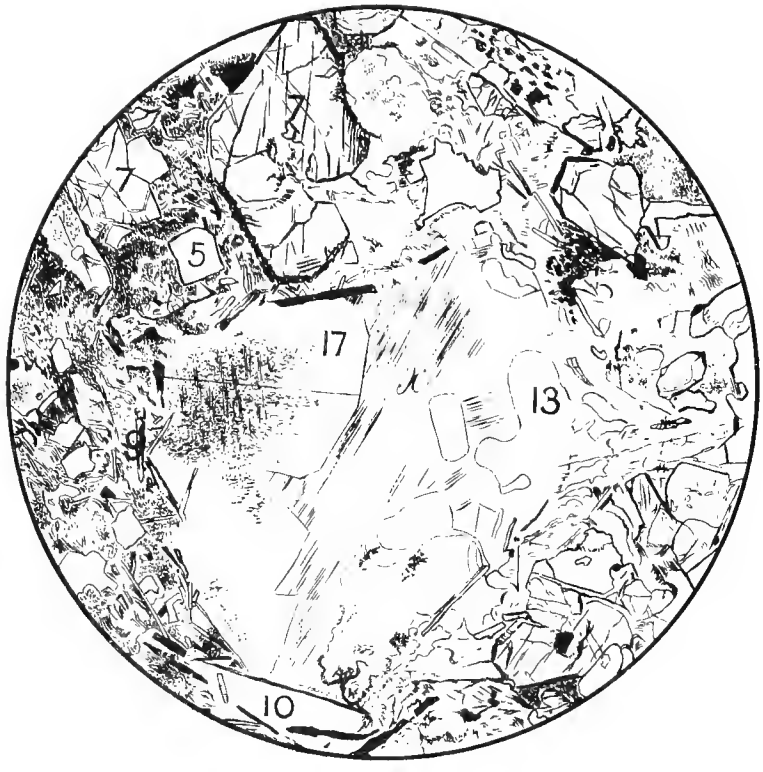


FIG. 2.

PLATE XXII.

FIG. 1.

ANALCIME-DIABASE.

CAR CRAIG, FIRTH OF FORTH.

Magnified 25 diameters.

The minerals represented are augite (7), plagioclase (10), magnetite (5) brown mica (9), analcime (17) and viridite (13). An undetermined zeolite (x) is also represented.

The augite varies in tint from nearly colourless to violet-brown. The coloured varieties are markedly pleochroic in violet-brown and yellowish brown tints. The plagioclase is much decomposed, and rarely shows well-marked structure. Analcime is very abundant in the rock. The undetermined zeolite gives straight extinction and possesses strong double refraction. The major axis of depolarisation lies parallel with the length of the section. The brown mica is abundant in the most altered portions of the rock. Its boundaries are often vague and ill defined. The extraordinary abundance of analcime seems to imply the existence of nepheline or a felspar rich in soda. This rock might also be called a teschenite.

FIG. 2.

MELAPHYRE.

NEAR POOR HOUSE, E. OF KINGHORN, FIFESHIRE.

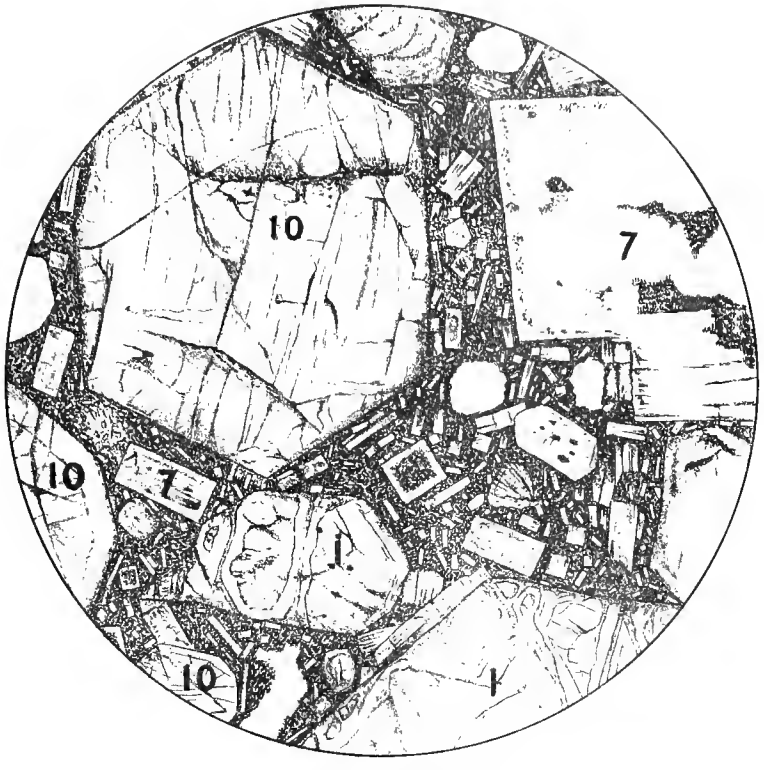
Magnified 50 diameters.

The substances represented are plagioclase (10), chlorite (12), pseudomorphs after olivine (6), interstitial matter (18), and magnetite.

The felspar gives lath-shaped sections and shows twin striation. The chlorite occurs in extremely minute scales often grouped in vermicular forms. The interstitial matter is crypto-crystalline. The serpentinous pseudomorphs after olivine are traversed by strings of magnetite which represent the original cracks from which serpentinisation proceeded. No augite is present in the rock. Its place is taken by chloritic aggregates. The term diabase is used for the altered holocrystalline dolerites; and melaphyre for the altered dolerites which originally contained interstitial matter.

KEY PLATE 23

FIG 1



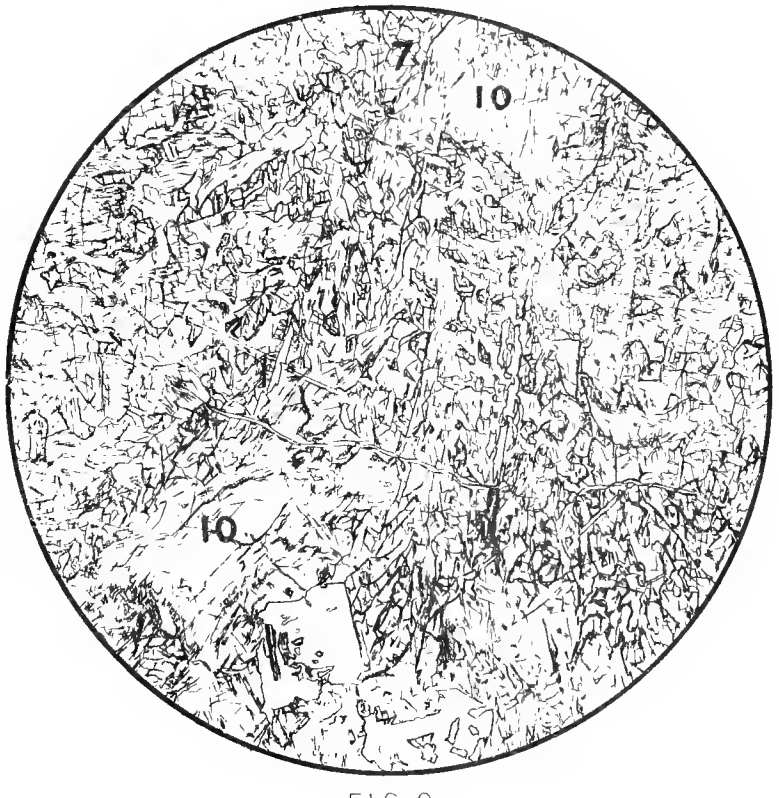


FIG 2

PLATE XXIII.

FIG. I.

PORPHYRITIC BASALT.

THE LION'S HAUNCH. ARTHUR'S SEAT, EDINBURGH.

Magnified 25 diameters.

The porphyritic constituents are plagioclase (10), augite (7), and olivine (1). The constituents of the ground-mass are plagioclase, magnetite, augite grains and crystals.

A section of augite cut somewhat oblique to the vertical axis occupies the upper part of the figure to the left. On the right is a portion of one of the porphyritic felspars. It contains large irregular inclusions of the ground-mass in the centre, and a zone of smaller inclusions round the margin. The felspars of the ground-mass often occur as microlites, with ragged or bifid terminations. Near the centre of the figure is a rectangular section of a skeleton felspar, with the interior occupied by the ground-mass of the rock. The augite microlites are too small to be distinctly represented in the figure. Isotropic glass, if present at all, must be so only in extremely small quantity.

The olivines are altered to serpentine along the cracks. This figure has appeared in "Cole's Studies in Microscopical Science."

FIG. II.

DOLERITE.

HAILSTONE HILL, ROWLEY, STAFFORDSHIRE.

Magnified 20 diameters.

The minerals represented are plagioclase (10), augite (7), and titaniferous iron ores.

The specimen from which the slide was taken is a coarse-grained portion of the dolerite represented in fig. 2, plate XI. The augite and felspar are intergrown exactly in the same manner as quartz and felspar in pegmatite and micro-pegmatite. Each mineral depolarises uniformly over large areas. The structure is due to the *simultaneous* crystallisation of felspar and augite, and differs therefore from the ophitic structure which is determined by *successive* crystallisation.

This rock is described by Mr. ALLPORT (Q.J.G.S., vol. XXX., p. 549), and the figure is drawn from his original slide.

KEY PLATE 24

FIG. 1

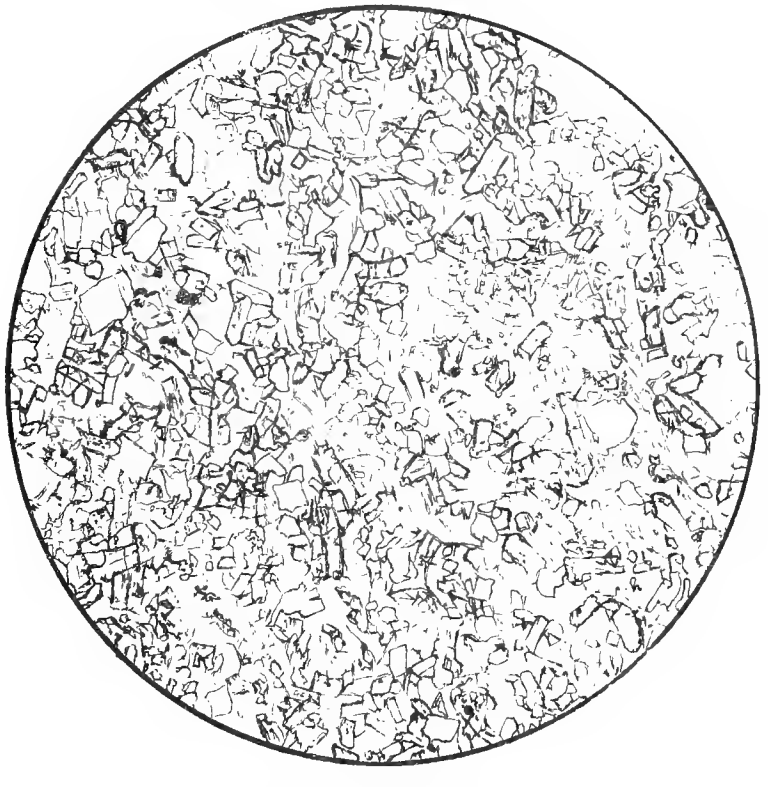


FIG. 2

PLATE XXIV.

FIG. I.

ANDESITIC BASALT.

ESKDALEMUIR, DUMFRIES.

Magnified 45 diameters.

The substances represented are felspar (10), augite (7), magnetite and brown glass. The felspars occur as simple individuals or binary twins. In some cases they show multiple twinning. The augite occurs in small granules, which sometimes show a decided approach to crystalline form. They are nearly colourless. The brown glass is perfectly isotropic. The colouring matter is not, however, uniformly distributed. The magnetite and augite are frequently surrounded by a nearly colourless space, as if the formation of these minerals had been accompanied by the abstraction of the colouring matter from the glass. The rock is vitreous in aspect. It has been described by Dr. GEIKIE (Proc. Roy. Phy. Soc., Edin., vol. V., 1880).

FIG. II.

BASALT.

TANSLEY HILL, DUDLEY, STAFFORDSHIRE.

Magnified 200 diameters.

The minerals represented are magnetite, minute augite crystals and felspar microlites. There may be also a little colourless glass.

This slide represents the character of the ground-mass of those basalts which contain minute crystals as distinguished from those which contain only granules of augite. The ultimate ground-mass is essentially felspathic, and under crossed nicols splits up into an aggregate of extremely minute felspar microlites and plates. It is very difficult to be certain as to the existence of any isotropic interstitial matter. If it exists it is perfectly colourless, like the felspar, and present only in very small quantity. This type of ground-mass is not known at present from the Tertiary Basalts of the Brito-Icelandic province, but is extremely common in the Tertiary Basalts of the Continent (*e.g.*, the Bohemian Basalts), and in the carboniferous Basalts of the Midland Valley of Scotland, and the neighbourhood of Limerick, in Ireland. In many cases (*e.g.*, rock near Dunsapie Loch, Edinburgh, and Craig of Neilston, Renfrewshire) the microlites of augite are much longer in proportion to their breadth than in this figure.

The rock of Tansley Hill is rendered micro-porphyritic by the occurrence of larger felspars than any represented in the figure. It will be observed that in this figure a very high magnifying power has been used.

KEY PLATE. 25.

FIG. 1.

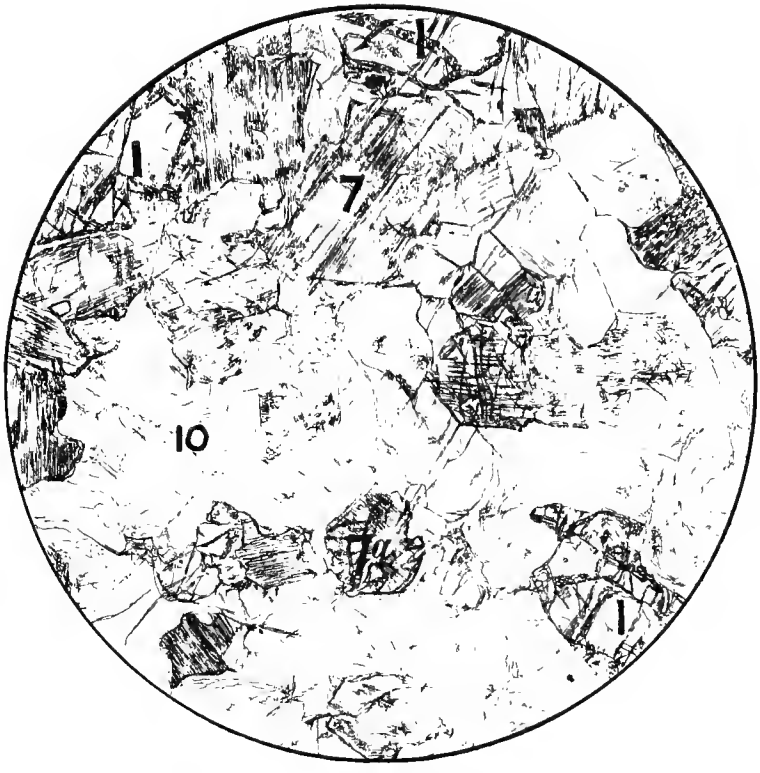


FIG. 2.

PLATE XXV.

FIGS. 1 and 2.

OLIVINE-GABBRO.

LOCH CORUISK, SKYE.

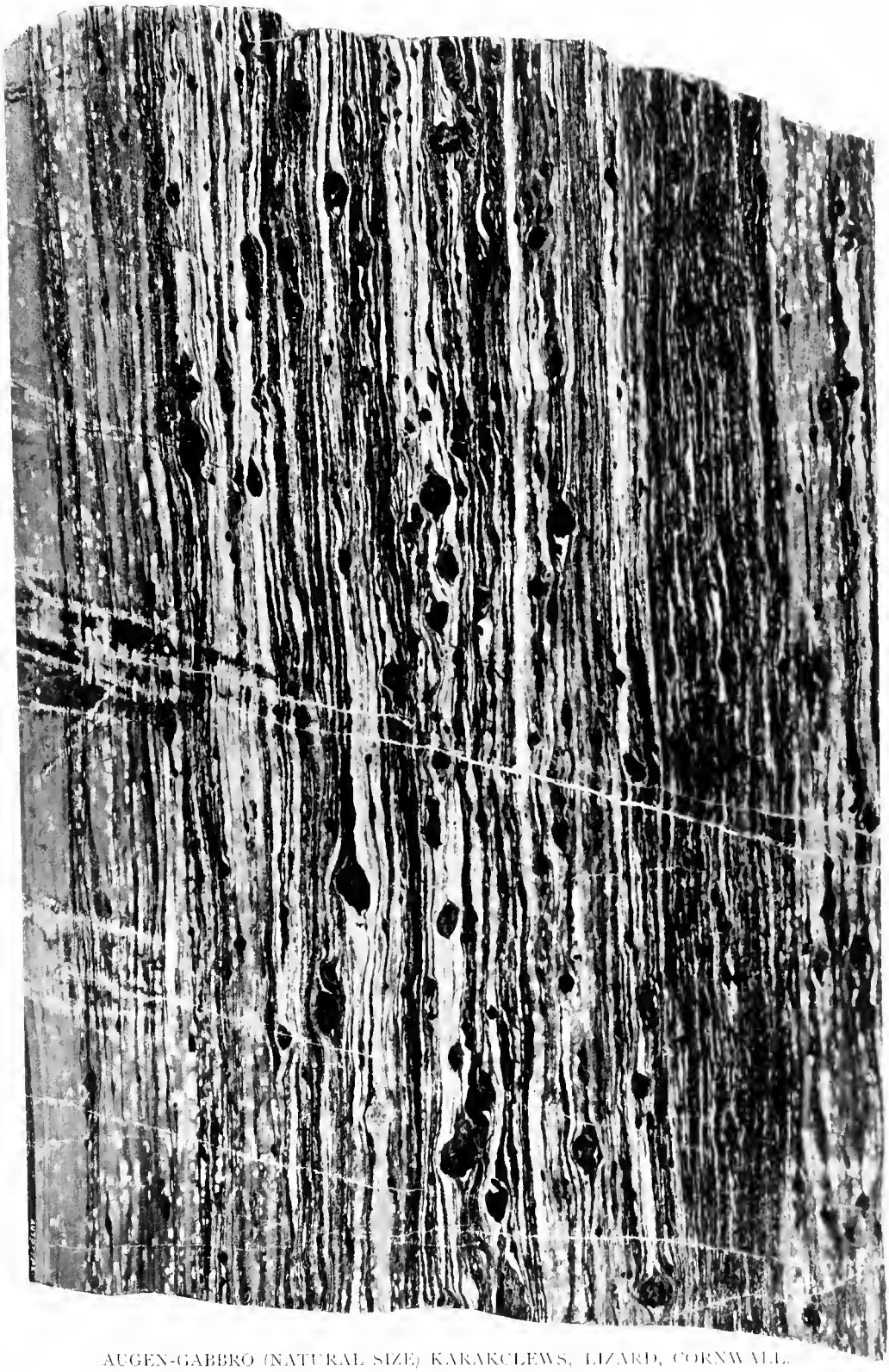
Magnified 25 diameters. Fig. 1, Ordinary light; Fig. 2, under crossed nicols.

The minerals represented are plagioclase (10), diallage (7) and olivine (1).

These figures represent the granitic structure in its typical development. The rocks are of Tertiary age. They have been described by Professor JUDD (Q.J.G.S., Vol. XLII., 1886, p. 50).

7*a* is a cross-section of a pyroxene showing the prismatic cleavages and also a separation parallel to the one of the vertical pinacoids.

Note.—The section is thicker than those generally employed so that the felspars polarize in brilliant colours instead of neutral tints.



AUGEN-GABBRO (NATURAL SIZE) KARAKCLEWS, LIZARD, CORNWALL.

PLATE XXVI.

AUGEN-GABBRO.

(Natural size).

KARAKCLEWS.

This plate represents the appearance of a polished surface of foliated gabbro. The "eyes" are formed of diallage. The dark bands are mainly composed of green hornblende; the white bands and streaks of the so-called saussurite.

The white spots seen in certain parts of the plate represent an undetermined substance which is almost constantly present in the Lizard gabbros. It appears in the glassy felspar of the comparatively unaltered rocks and increases in amount as the felspar passes into the condition of saussurite.

The parallel structure in this rock is regarded by the author as the result of the deformation by earth-stresses of an original mass of normal gabbro.

The slab is traversed by narrow veins which cut the planes of foliation at angles of about 15°

KEY PLATE 27

FIG 1

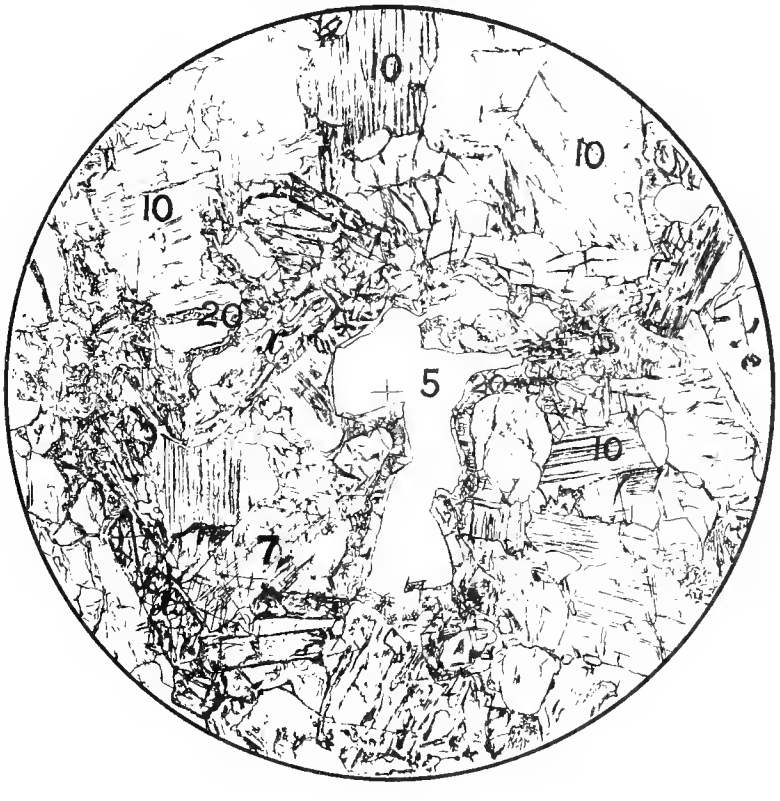


FIG 2

PLATE XXVII.

FIG. 1.

PYROXENE-HORNBLENDE-MAGNETITE ROCK.

SCOURIE, SUTHERLANDSHIRE.

Magnified 25 diameters. Drawn with polarizer only. Short axis N. & S.

The minerals represented are hypersthene (2), diallage or pseudo-hypersthene (7), hornblende (8), iron-ores (5), brown mica (9).

The structure of the rock is granitic. The different minerals interfere with each other. Although massive in habit the rock is probably an integral portion of the Hebridean gneissic system with which it is associated. The blue tint in the diallage and pseudo-hypersthene is much exaggerated in the figure.

FIG 2.

FELSPAR-PYROXENE-MAGNETITE-GARNET ROCK.

SCOURIE, SUTHERLANDSHIRE.

Magnified 25 diameters. Felspars represented under crossed nicols; the other minerals as they appear in ordinary light.

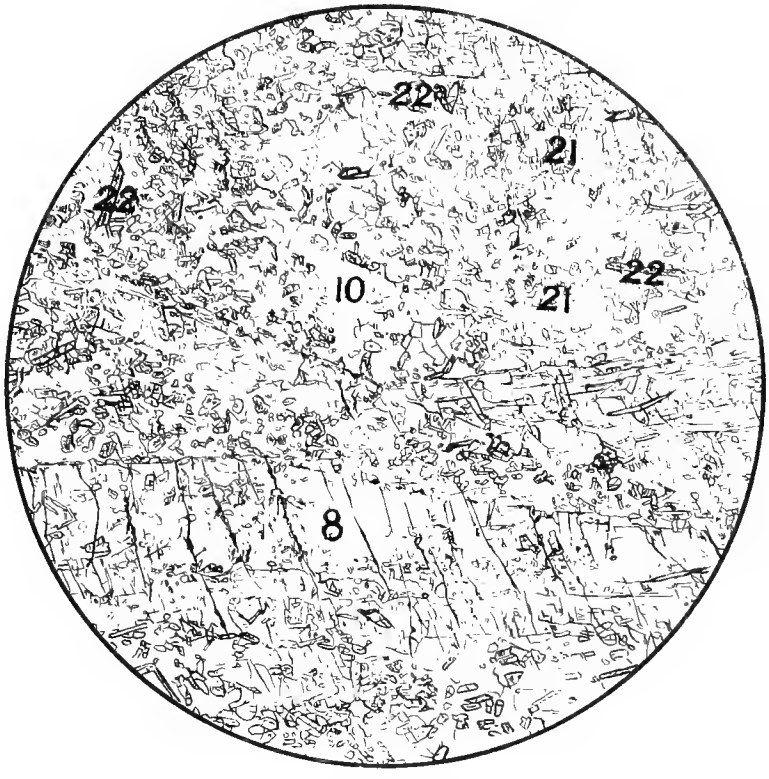
The minerals represented are plagioclase (10), green diallage (7), iron-ores (5), and garnet (20). There is also an undetermined mineral *x*.

The green diallage is similar to that of the Baltimore gabbro described by Mr. WILLIAMS. This diallage enters largely into the composition of the Hebridean gneissic system of Sutherlandshire. The garnet occurs in zones surrounding the iron-ore. That the mineral in question is garnet and not sphene is proved by the fact that it is perfectly isotropic.

The rock occurs under the same circumstances as the former.

KEY PLATE. 28.

FIG I



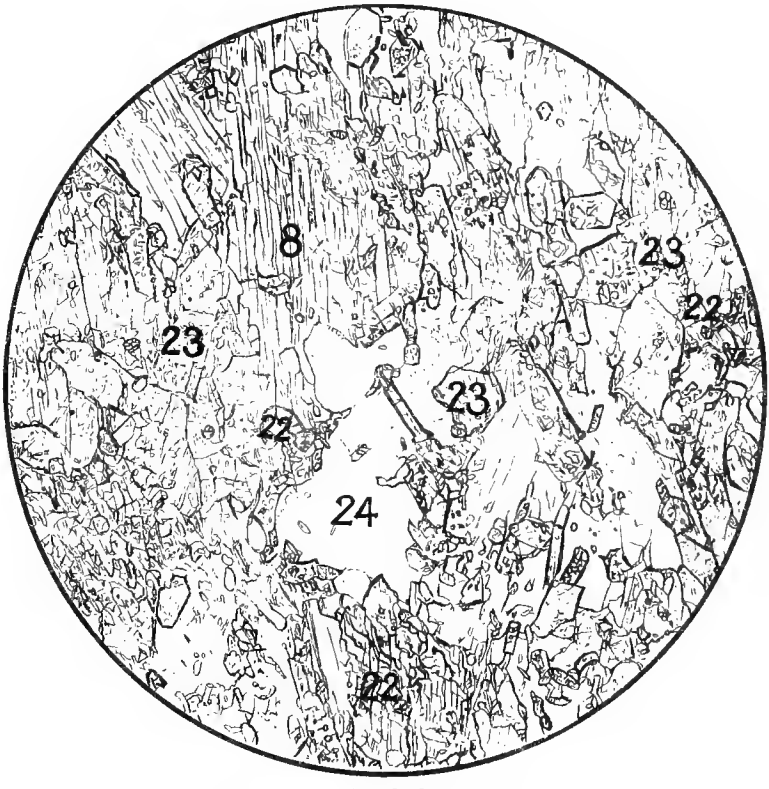


FIG.2.

PLATE XXVIII.

FIG. 1.

ACTINOLITE-SCHIST.

ELRIGG, STRATH ARDLE, PERTHSHIRE.

Magnified 50 diameters. Ordinary light.

The minerals represented are actinolite (8), zoisite? (21), felspar (10) and rutile (22).

The needles of actinolite lie, as it were, in a ground-mass composed of a granulitic aggregate of untwinned water-clear grains of a biaxial mineral (felspar). Small prisms and grains of a mineral with high refractive and low double-refractive power (zoisite) are thickly scattered through the slide and occur in the felspar-mosaic and also in the actinolite. The rutile occurs as crystals and grains. A knee-shaped twin (angle made by the principal axes of the two individuals 66°) is seen at 22*a*. The felspar-zoisite aggregate answers to the saussurite of Cathrein.

FIG. 2.

EPIDOTE-AMPHIBOLITE.

NEAR BLACK CROFT, GLEN LYON, PERTHSHIRE.

Magnified 50 diameters. Drawn with polarizer only; short axis N. and S.

The minerals represented are hornblende (8), epidote (23), quartz (24) and rutile (22).

The hornblende belongs to two varieties so far as colour is concerned. In the one variety; a = pale yellowish brown, β = deep green, γ = blue or bluish green; in the other a = pale yellowish brown, β and γ = deep brown. These two varieties are intergrown. Epidote occurs as idiomorphic crystals and is present as inclusions in both hornblende and quartz. The quartz is present in granular aggregates. It forms a very small portion of the rock. Rutile occurs for the most part in grains.

KEY PLATE 29

FIG.1

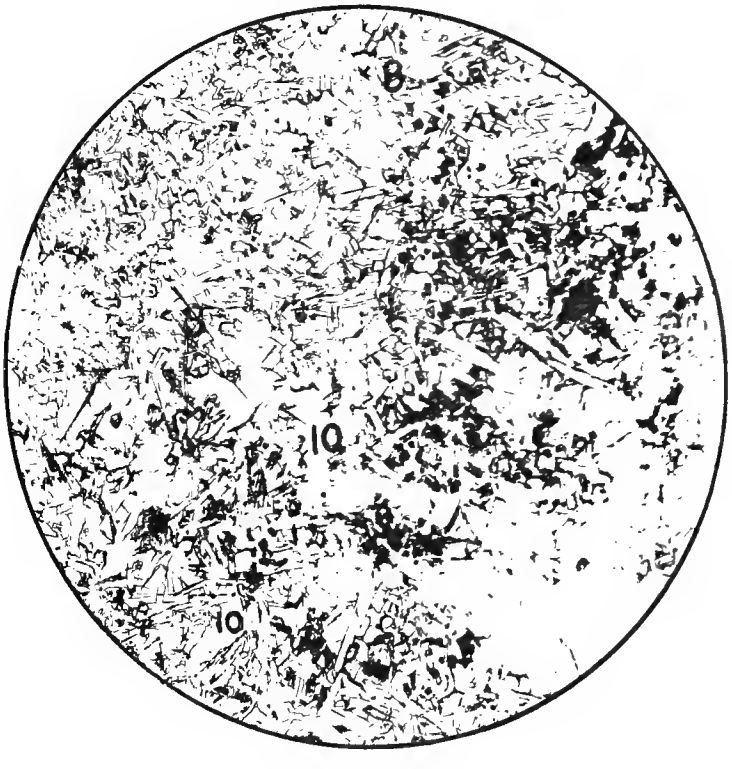


FIG.2.

PLATE XXIX.

FIG. 1.

OLIVINE-DIORITE.

CHILVERS COTON, WARWICKSHIRE.

Magnified 50 diameters.

The figure represents a portion of an irregular ophitic plate of brown hornblende (8) containing lath-shaped felspars (10), green alteration products and magnetite. The remaining portion of the slide from which the figure is taken consists of green and colourless hornblende, cloudy granular pseudomorphs after felspar, pseudomorphs after olivine and calcite in good-sized plates.

FIG. 2.

DIORITE.

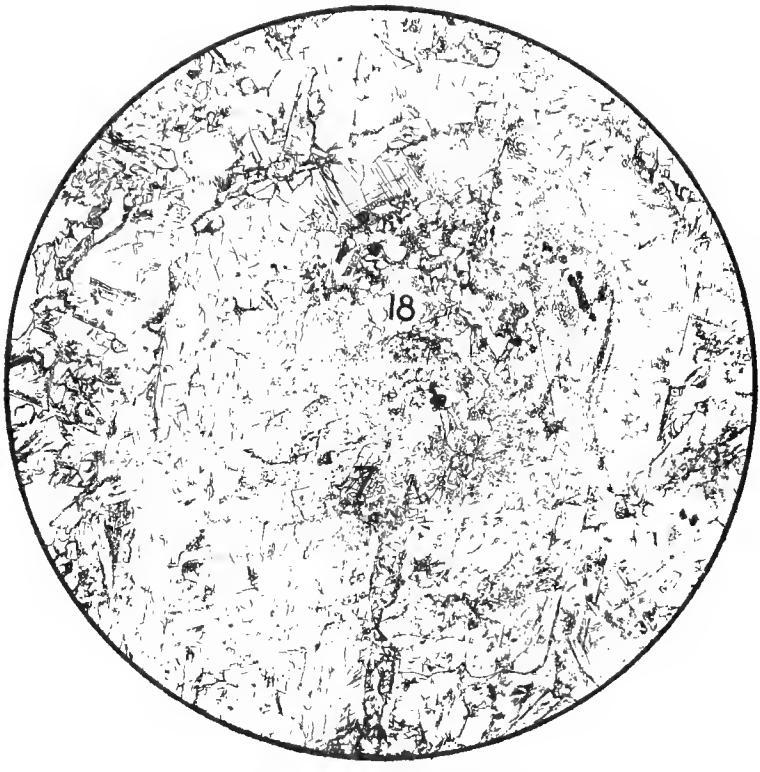
MARSTON JABET, WARWICKSHIRE.

The minerals represented are brown hornblende (8), magnetite (5) and plagioclase (10).

The hornblende occurs in long prisms which are idiomorphic in the prismatic zone, showing the forms (110) and (010). The matrix in which the hornblende lies is an aggregate of perfectly fresh felspar which occurs in grains and shows lamellar twinning under crossed nicols. The rocks represented in this plate have been described by Mr. ALLPORT (Q.J.G.S., Vol. XXXV., 1879, p. 367), and the figures have been drawn from his original slides.

KEY PLATE 30

FIG.1



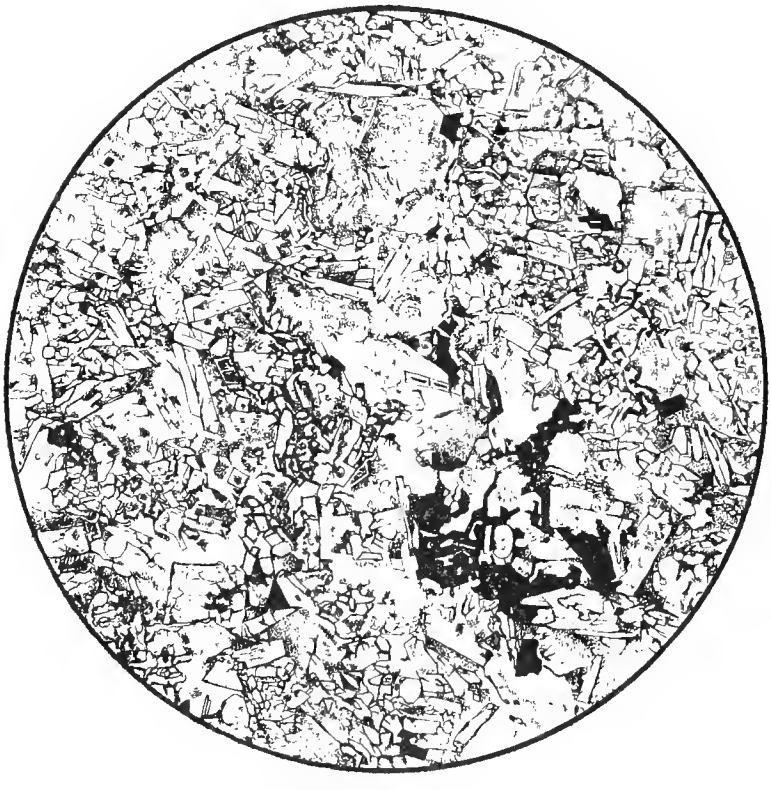


FIG.2

PLATE XXX.

FIGS. 1 and 2.

ANDESITIC DOLERITE.

BARWICK QUARRY, NEAR PRESTON, ON THE TEES.

Magnified 25 diameters. Ordinary light.

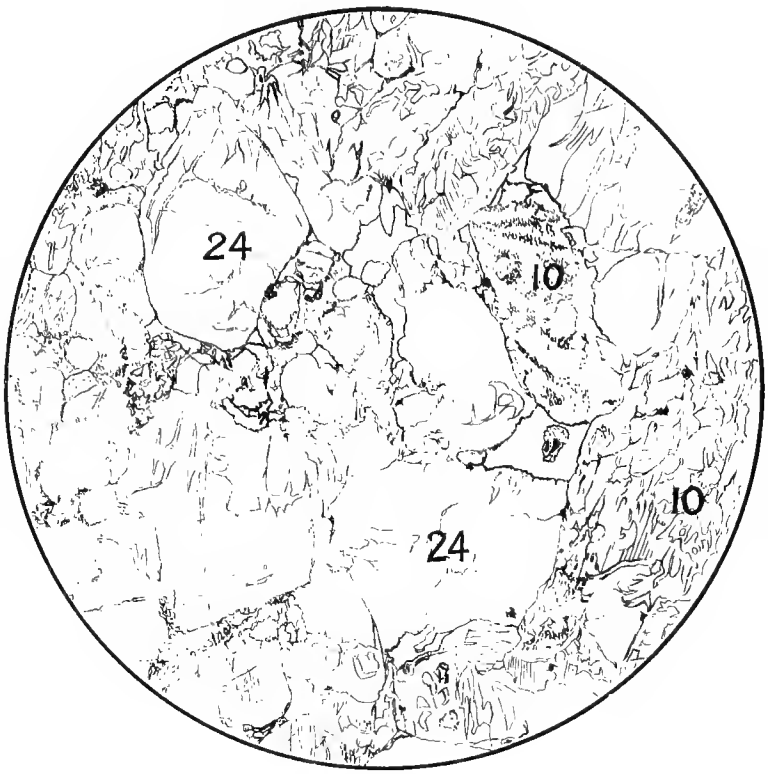
Fig. 1 represents a section of one of the large porphyritic felspars (labradorite). This felspar contains large inclusions of the ground-mass and grains of augite (7).

Fig. 2 represents the microscopic structure of the ground-mass in which the felspars lie embedded. The substances present are plagioclase, augite, magnetite (5), pyrites (19) and interstitial matter. The augite occurs in small, almost colourless granules which are not well seen in the figure. The pyrite is drawn as it appears in transmitted light; by reflected light it shows the characteristic yellow metallic lustre. The brown interstitial matter gives a vague reaction with crossed nicols. It contains minute and often feathery microlites of felspar. The skeleton felspars represented in Fig. 7, page 15, occur in this slide.

The dyke is almost certainly of Tertiary age. It cuts Oolitic rocks and alters them.

KEY PLATE 31.

FIG. 1.



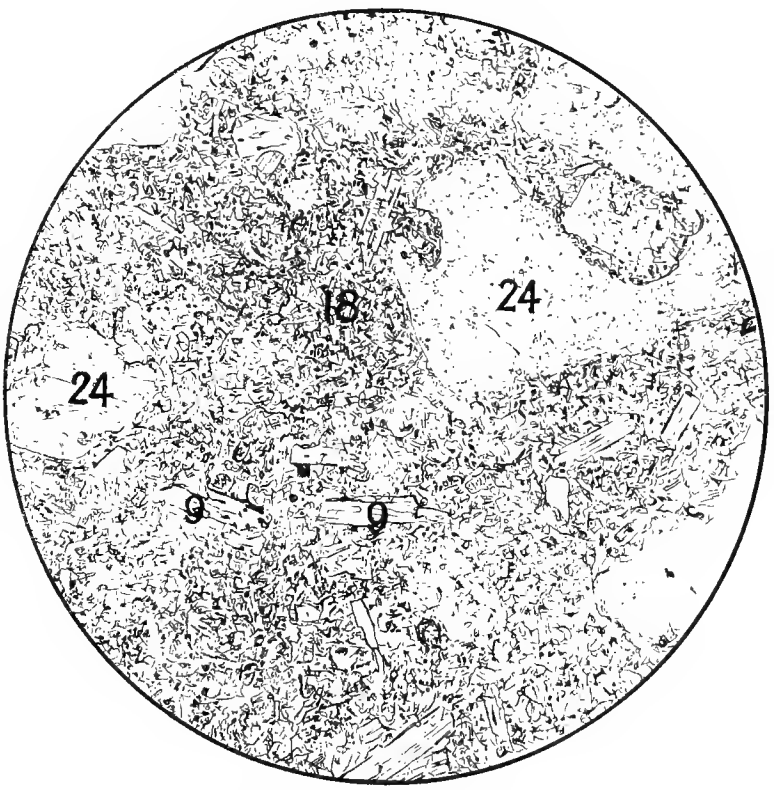


FIG. 2.

PLATE XXXI.

FIG. 1.

QUARTZ-FELSPAR GRIT.

LOCH MAREE, ROSS.

Magnified 25 diameters. Ordinary light.

The principal constituents are quartz (24) and felspar (10).

The felspar in almost all cases retains its individual action under crossed nicols and generally shows microperthitic or microlinic structures. The opaque patches appear red by reflected light and are evidently local accumulations of ferric oxide. The rock is of pre-Ordovician age.

FIG. 2.

QUARTZ-FELSITE.

RIDLEES BURN, CHEVIOT DISTRICT.

Magnified 50 diameters. Polarizer only. Short axis N. & S.

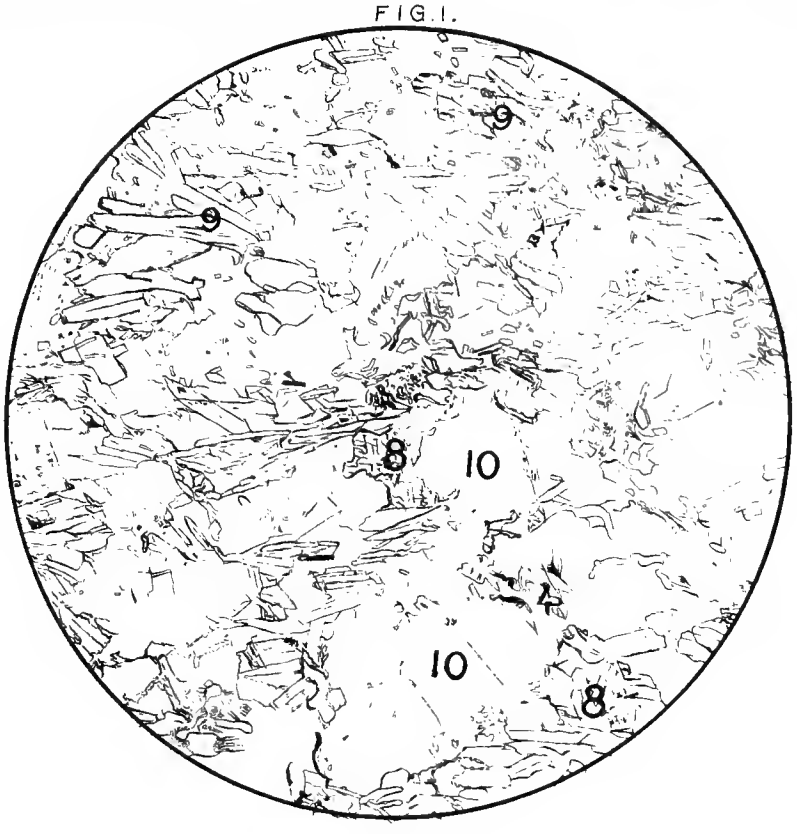
The substances represented are quartz (24), biotite (9) and interstitial matter.

The quartz occurs in the corroded forms characteristic of the quartz-porphyries. The interstitial matter is micro- or crypto-crystalline and contains minute flecks and granules of ferrite.

The rock forms a dyke in the Cheviot porphyrites.

KEY PLATE. 32.

FIG. 1.



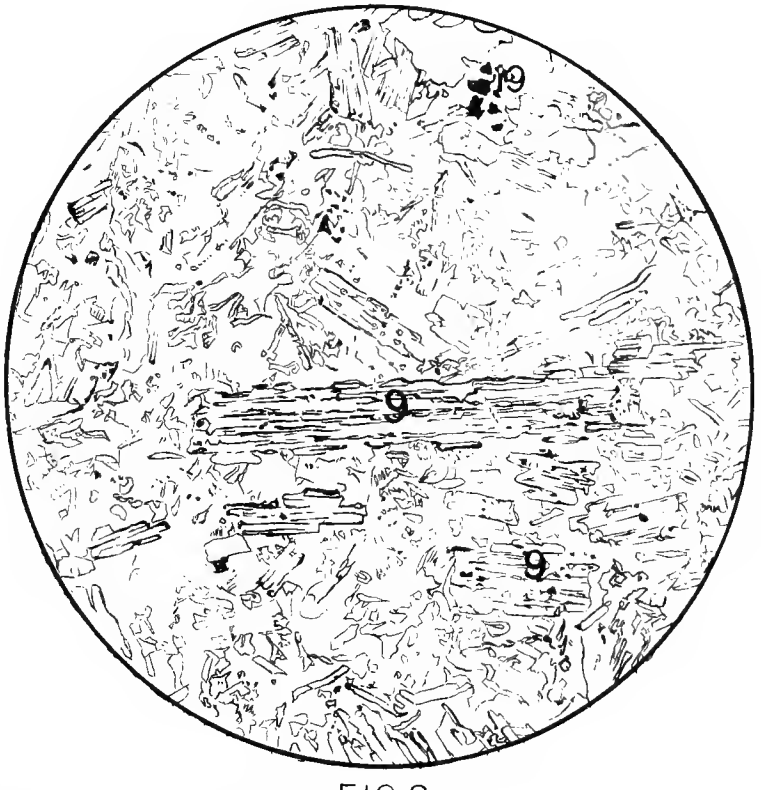


FIG. 2.

PLATE XXXII.

FIG. 1.

MICA-DIORITE.

PEN VOOSE, THE LIZARD, CORNWALL.

Magnified 25 diameters. Drawn with polarizer only; short axis right and left

The minerals represented are reddish-brown mica (9), felspar (10) and hornblende (8).

There is a rude kind of parallelism in the arrangement of the mica flakes. The colourless portions of the figure split up under crossed nicols into an aggregate of large and small grains. These are sometimes striated; more frequently unstriated. Sections cut approximately at right angles to an optic axis give a biaxial figure, thus proving that the mineral in question is not quartz. Hornblende occurs sparingly and is allotriomorphic. In other portions of the slide there are plagioclase crystals with zonal structure; the interior of these crystals is more altered than the exterior.

The rock in question occurs in association with gabbro and granite.

FIG. 2.

MICA-TRAP.

SWINDALE BECK, NEAR APPLEBY.

Magnified 50 diameters. Drawn with polarizer only; short axis right and left

The only conspicuous minerals represented are a dark mica (9) and pyrites (19).

The ground-mass is an aggregate of quartz, decomposed felspar and calcite dust.

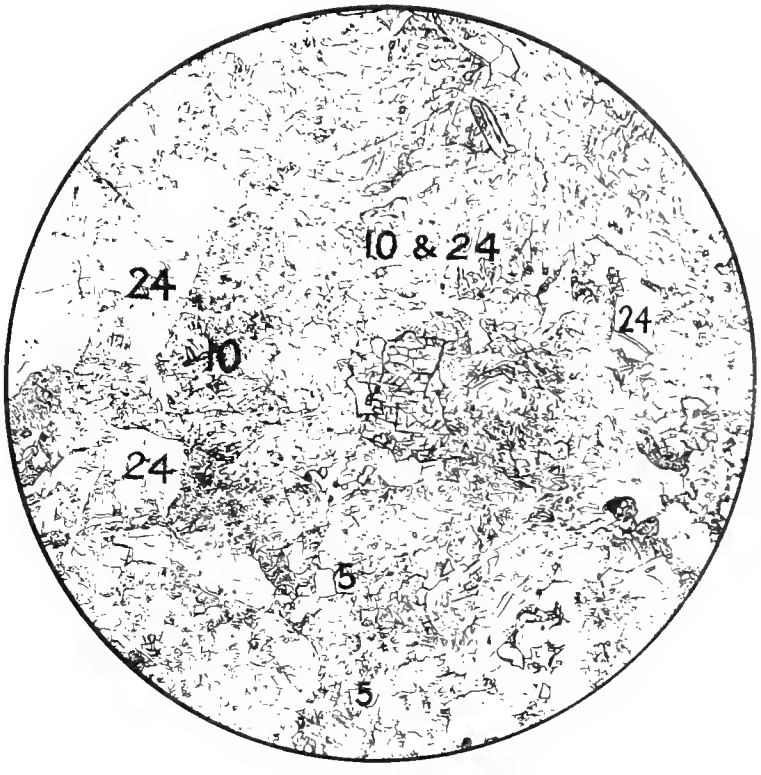
This figure illustrates the characteristic form of the mica of the mica-traps. It is biaxial with a small optic axial angle. Sections at right angles to the basal plane usually show a lamellar structure due to twinning.

Pyrite occurs in irregular patches. The felspathic constituent which doubtless entered largely into the composition of the rock has been so altered that it is impossible to determine its character. Quartz occurs in small grains and is probably a secondary product.

The rock forms a dyke in Lower Palæozoic strata.

KEY PLATE. 33.

FIG. 1.



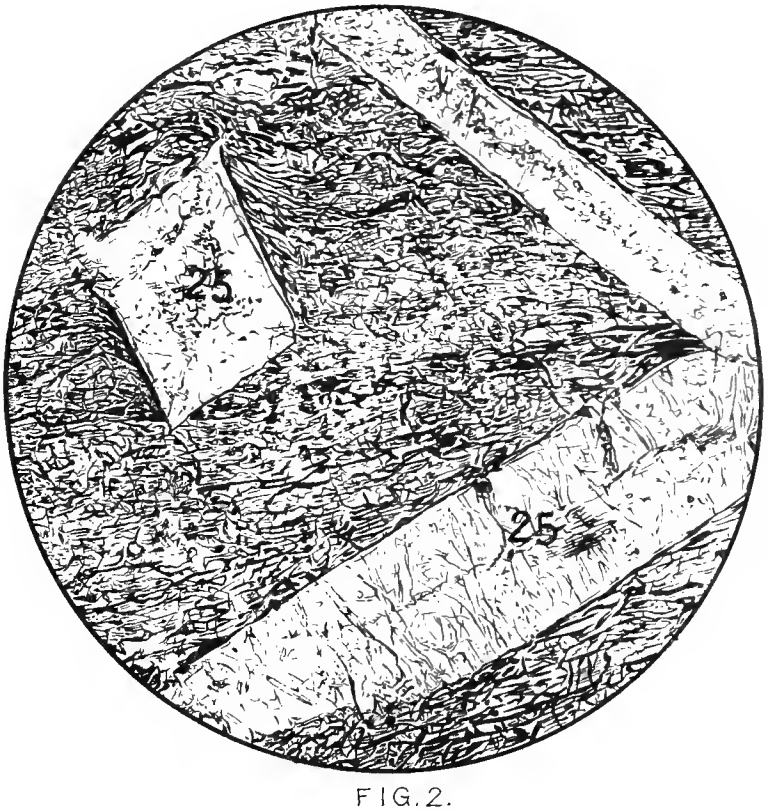


FIG. 2.

PLATE XXXIII.

FIG. 1.

AUGITE-GRANOPHYRE.

BASE OF CRAIG CRAGGEN, MULL.

Magnified 50 diameters. Ordinary light.

The minerals represented are felspar (10), quartz (24), augite (7) and magnetite (5).

The felspar of this rock is mostly unstriated and often occurs as Carlsbad twins. It is present as idiomorphic crystals and also as a constituent of micro-pegmatite (10 and 24). The felspar of the micro-pegmatite surrounding a felspar-crystal extinguishes simultaneously with the crystal, and when the crystal is a Carlsbad twin the trace of the twin plane may be followed into the micro-pegmatite. The quartz occurs as more or less independent grains and also as a constituent of micro-pegmatite. The augite is green in colour and allotriomorphic. The grain in the centre is cut so that the principal cleavages intersect approximately at right angles. It gives an optic axis in convergent light.

FIG. 2.

CHIASTOLITE-SLATE.

SKIDDAW, LAKE DISTRICT.

Magnified 50 diameters. Drawn with polarizer only; short axis right and left.

The minerals represented are chiastolite (25), dark brown mica, white mica, quartz, iron-ores.

The figure shows one transverse and two longitudinal sections of chiastolite prisms. The transverse section is not strictly at right angles to the vertical axis. The characteristic inclusions of black pigment are seen in the central portions of the section.

The two micas occur both in large and small flakes. Quartz is present in the form of irregular grains the boundaries of which can only be recognized under crossed nicols. Iron-ores and possibly carbonaceous matter are represented by opaque granules.

The rock is a fossiliferous (Arenig) slate altered by contact with granite.

KEY PLATE.34.

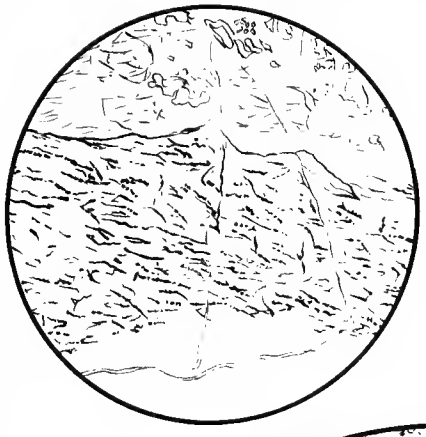
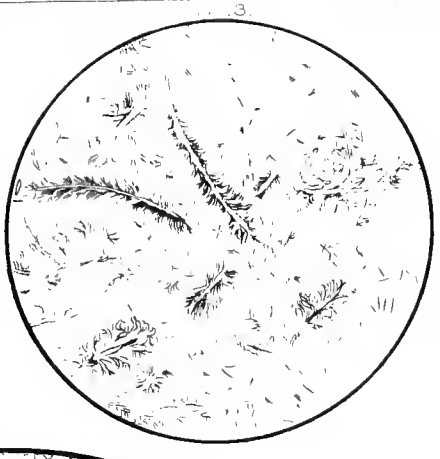


FIG.2



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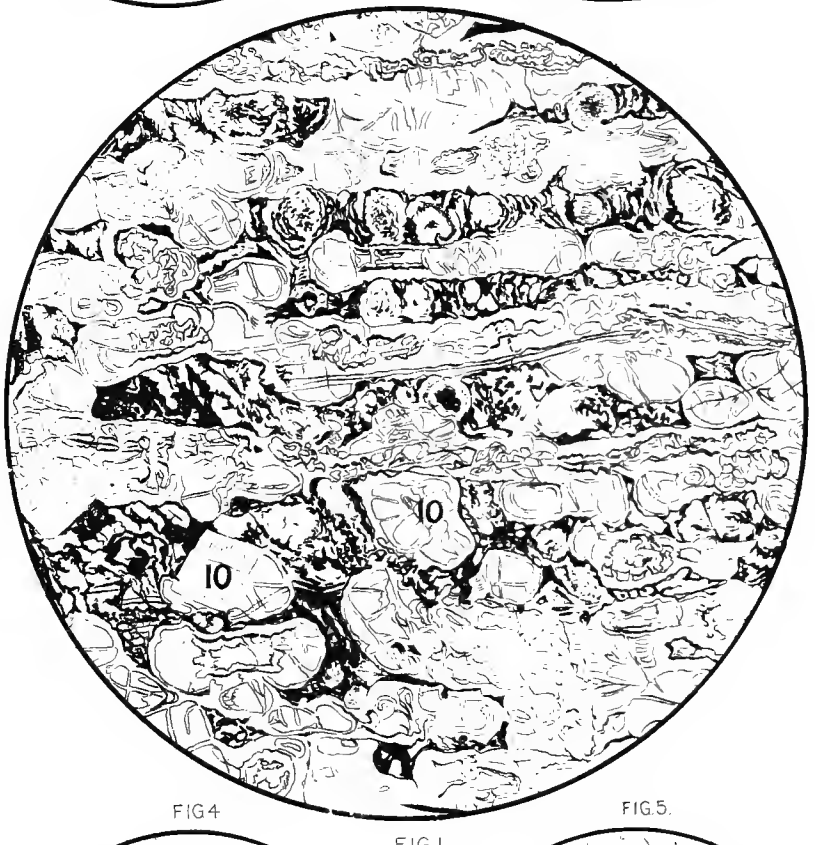


FIG.4

FIG.1

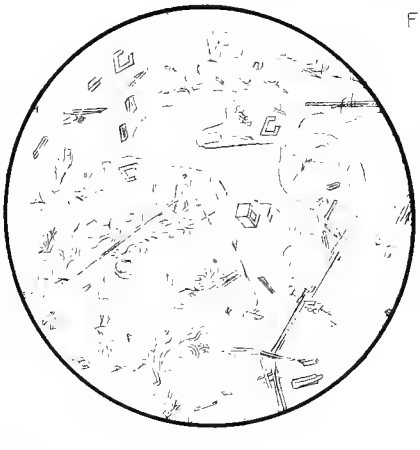


FIG.5.

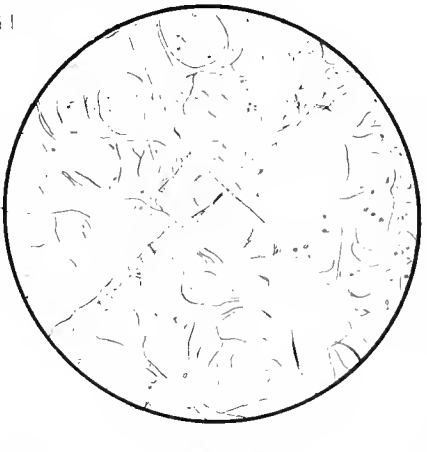


PLATE XXXIV.

SPHERULITIC FELSITE.

THE LEA ROCK; NEAR WELLINGTON, SHROPSHIRE.

FIG. 1.

Magnified 10 diameters; ordinary light.

The only definitely recognizable mineral represented in the figure is felspar (10). This is mostly striated. The main mass of the rock is composed of perlitic and non-perlitic bands. The perlitic cracks are picked out by green alteration products which are incapable of precise determination. Under crossed nicols the perlitic portions give a micro-crystalline reaction. The non-perlitic bands and patches are coloured red by ferrite. They sometimes show traces of radial structure and when this is the case each radial aggregate behaves as a positive spherulite. Where a band terminates the end is usually swollen. The red colouring matter is disseminated unequally in the red patches and bands. There is always an inner deeply-coloured portion and an outer feebly-coloured portion; the latter gives only a very feeble reaction under crossed nicols.

This rock was first described by Mr. ALLPORT (Q.J.G.S., Vol. XXXIII., 1877, p. 449). It is older than strata containing upper Cambrian fossils and is therefore presumably of pre-Cambrian age.

FIG. 2.

PORTION OF THE ROCK REPRESENTED IN FIG. 1.

This figure shows the trichites and margarites which occur in the rock. They are best defined in the light red bands.

FIGS. 3 & 4.

PITCHSTONE.

ARRAN.

Magnified 100 diameters. Ordinary light.

The base is a colourless glass. The dusty appearance is due to extremely minute acicular microlites. These are aggregated in places so as to produce feathery forms. That the microlites are hornblende (not augite) is proved by Fig. 4. The larger ones are composed of long narrow laths which are joined together so as to form a hollow crystal having the angles of hornblende. Very often the external boundary of the skeleton crystal is incomplete so that there is a free communication between the glass in the interior and that surrounding the microlites.

FIG. 5.

PERLITIC PITCHSTONE.

ISLE OF EIGG.

Magnified 20 diameters. Ordinary light.

The centre of the figure is occupied by a crystal of sanidine. Both glass and crystal are traversed by a crack, evidently formed during the final stages of consolidation. The walls of the crack became separated by contraction more in the glass than in the crystal. The space thus formed became filled with a colourless substance distinct from that forming the main mass of the glass.

KEY PLATE 35.

FIG. 1

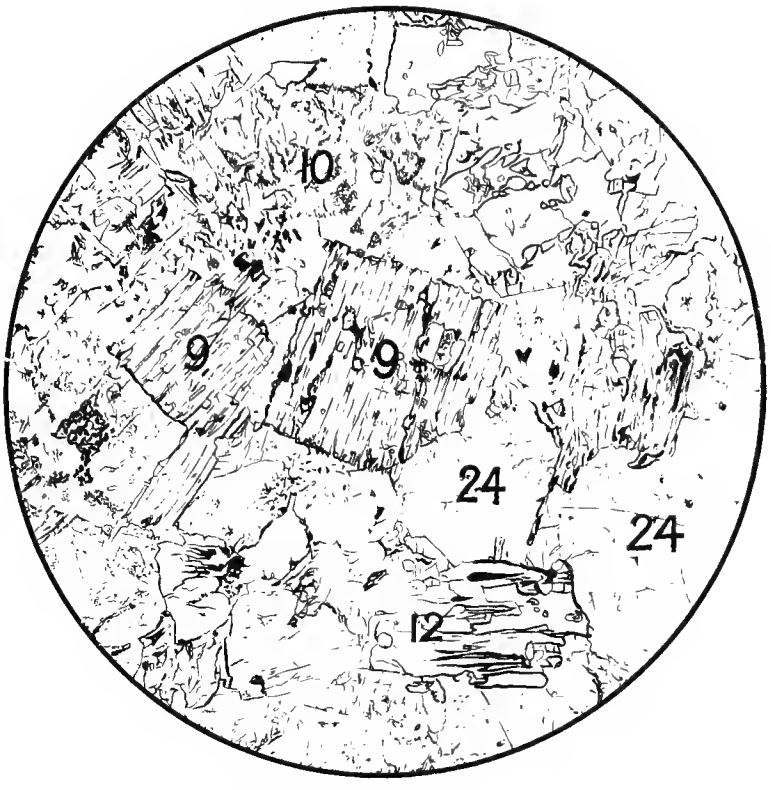


FIG 2.

PLATE XXXV.

FIG. 1.

BIOTITE-GRANITE (GRANITITE.)

SHAP.

Magnified 30 diameters. Drawn with polarizer only; short axis right and left.

The minerals represented are quartz (24), felspar (10), dark mica (9), chlorite (12) and apatite.

The dark mica occurs in hexagonal plates. In the upper part of the figure to the right is a hexagonal section which has been more or less changed to chlorite. The brown portions of this section give a uniaxial, or nearly uniaxial, figure in convergent light; the green portions do not give a distinct figure.

The central part of the drawing is occupied by a section of biotite at right-angles to the basal cleavage. It appears of a light brown tint because the traces of the cleavage are nearly at right angles to the short axis of the polarizer. The colourless spots in this and in the other sections are sections of apatite. The section of biotite to the left is cut in the same direction as the last, but is of a darker colour because the cleavage cracks make a smaller angle with the vibration plane of the light (short axis of the polarizer). The section in the lower part of the figure is also at right angles to the basal plane. The dark parts are unaltered biotite; the dark colour being due to the intense absorption of the rays vibrating right and left and therefore parallel with the cleavage cracks.

The quartz and felspar are mostly devoid of crystalline form. In other parts of the slide felspar (orthoclase) plays the rôle of matrix to the quartz; strings of felspar-substance lying between detached grains of quartz.

Apatite occurs in well-crystallized hexagonal prisms and is especially abundant as inclusions in the biotite.

This granite is intrusive in Ordovician strata.

FIG. 2.

ENSTATITE-DIORITE. PENMAENMAWR.

Magnified 30 diameters, crossed nicols.

This figure shows felspar (10), quartz (24), rhombic pyroxene (2) and iron ores.

Plagioclase felspar occurs in idiomorphic crystals which give lath-shaped sections. These sections show both multiple and binary twinning. Untwinned felspar, probably orthoclase, occurs intergrown with quartz to form micro-pegmatite. The rhombic pyroxene is not well represented in the portion figured. It occurs in more or less idiomorphic crystals, but the angles are frequently rounded. It is green in colour when viewed in ordinary light and sometimes shows a fibrous structure. These features are probably the result of alteration. It is interesting to note that this section is ground to such a thickness that the maximum tint given by the quartz is the yellow of the first order. Orthoclase, in sections of such thickness, never polarizes in colour in consequence of its slightly lower double-refraction.

Micro-pegmatite and quartz play the rôle of ground-mass to the other constituents.

This rock was described by Mr. J. A. PHILLIPS (Q.J.G.S., Vol. XXXIII., 1877, p. 123). It is intrusive in Lower Palæozoic strata.

KEY PLATE 36

FIG. 1

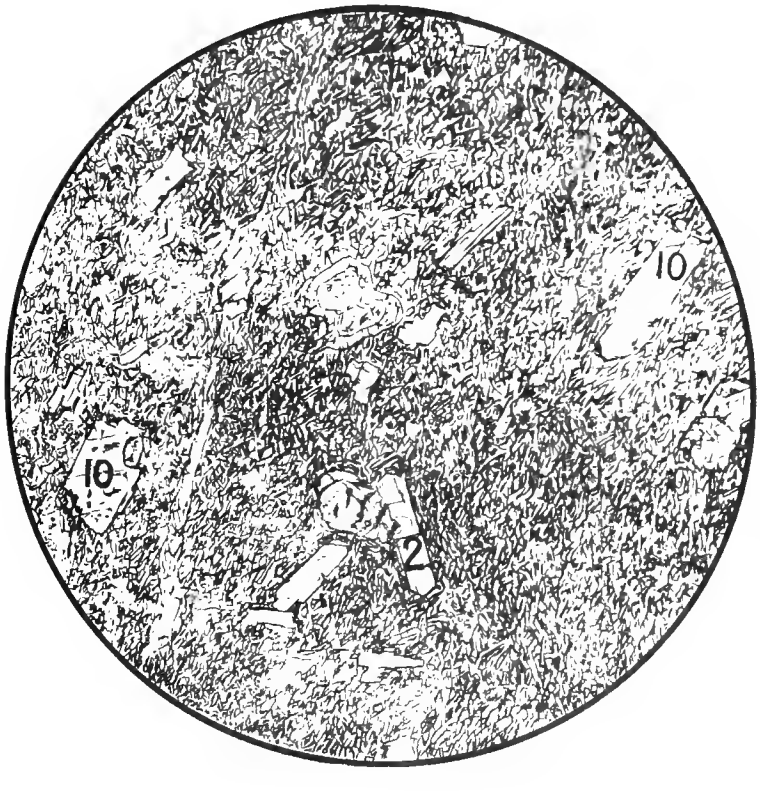


PLATE XXXVI.

FIG. 1.

ENSTATITE-AUGITE-ANDESITE.

HALF-A-MILE ABOVE WINDY HAUGH ON THE COQUET; CHEVIOT DISTRICT.

Magnified 25 diameters. Ordinary light.

The porphyritic constituents are labradorite (10), enstatite (2), and augite (7).

The labradorite occurs in detached crystals and in groups. One group containing two augite-grains is represented in the lower part of the figure. The internal boundaries of the individuals forming a group are irregular; the external boundaries are formed by crystalline faces. The individual grains in a group are, therefore, idiomorphic externally and allotriomorphic internally.

The ground-mass is composed of a pale brown glass, small felspars, specks of opacite and minute hexagonal plates of hematite (eisen-glimmer). The latter, however, cannot be seen with the magnifying power employed. The red vein in the upper part of the figure is formed of opal, deeply stained with ferric oxide.

FIG. 2.

ENSTATITE-ANDESITE.

THE ALWIN; CHEVIOT DISTRICT.

Magnified 50 diameters. Ordinary light.

The constituents of this rock belong to three well marked periods. Those of the first period are labradorite (10), and enstatite (2). They constitute the porphyritic elements and are the only definitely recognizable minerals in the figure. A good longitudinal section of enstatite, with the characteristic terminations formed by two flat domes, is seen somewhat below the centre of the figure.

The constituents of the groundmass belong to the second period. They comprise oligoclase-microlites (giving straight or nearly straight extinction) magnetite grains and isotropic glass.

The brown colouring matter (ferric oxide) developed in certain places and especially along cracks is an alteration product and must be referred to the third period.

KEY PLATE. 37.

PLATE XXXVII.

FIG 1.

HORNBLENDE-ANDESITE.

TOP OF BEINN NEVIS.

Magnified 50 diameters. Ordinary light.

The porphyritic constituents are plagioclase (10), and hornblende (8).

The large plagioclase crystal is completely honeycombed with inclusions. The hornblende is idiomorphic. The section of the small individual to the right of the group is bounded by the forms (110) and (010). The groundmass is composed of felspar microlites, specks of iron-oxide, glass and indefinite double refracting matter. The rock is probably of Upper Palæozoic age.

FIG. 2.

ENSTATITE-PORPHYRITE.

HALF-A-MILE ABOVE SHILLMOOR ; CHEVIOT DISTRICT.

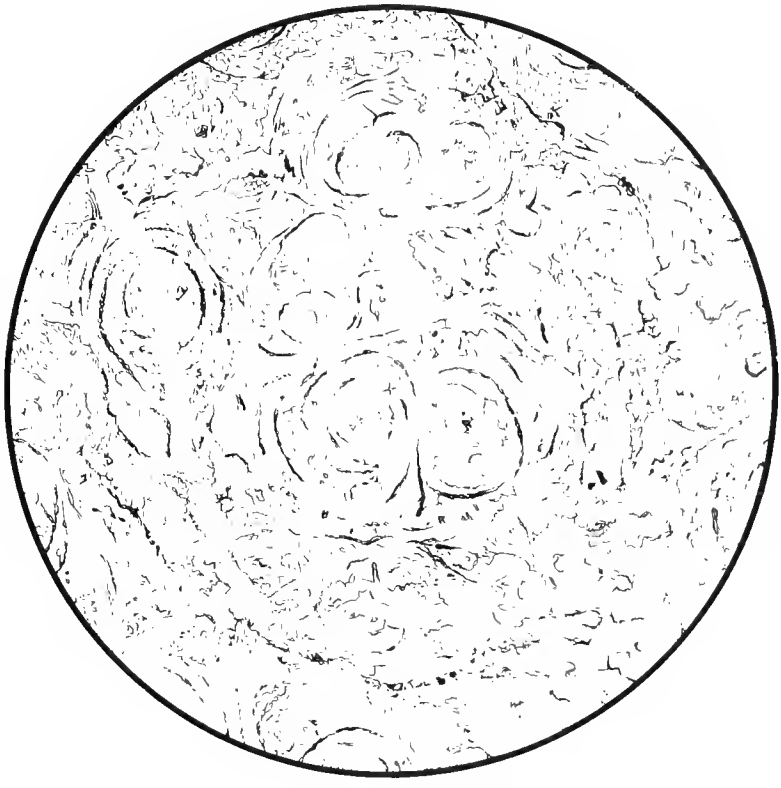
Magnified 25 diameters. Ordinary light.

The porphyritic constituents are labradorite (10), and enstatite (2). The latter mineral is now represented by fibrous pseudomorphs (? bastite) which sometimes polarize as aggregates and sometimes as individuals.

The groundmass is a glass crowded with felspar microlites and magnetite granules. The labradorite crystals contain irregular inclusions of the groundmass.

KEY PLATE.38.

FIG I



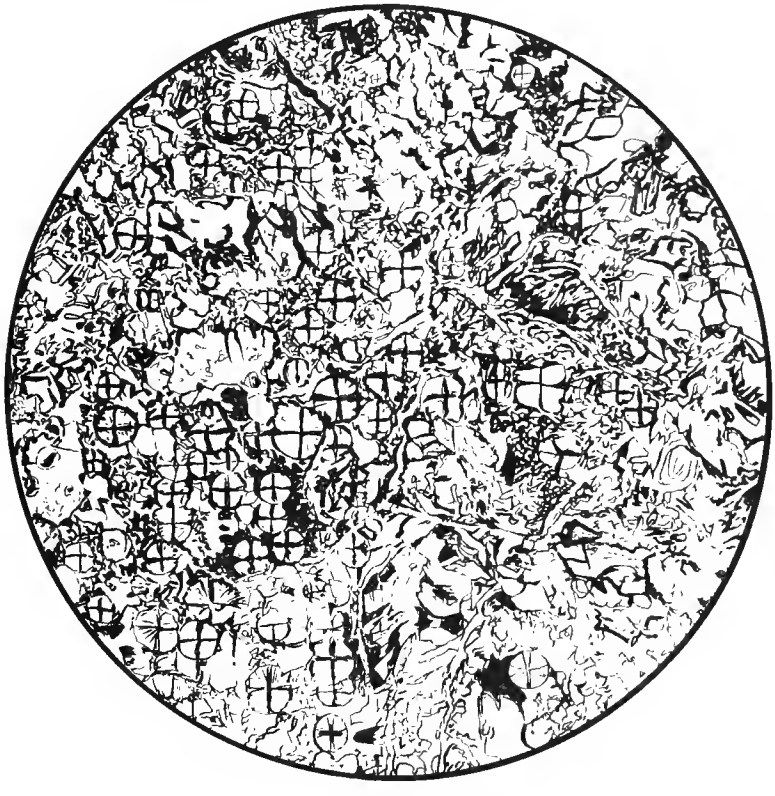


FIG.2.

PLATE XXXVIII.

PERLITIC FELSITE.

TILL'S HOLE, LONG SLEDDALE, WESTMORELAND.

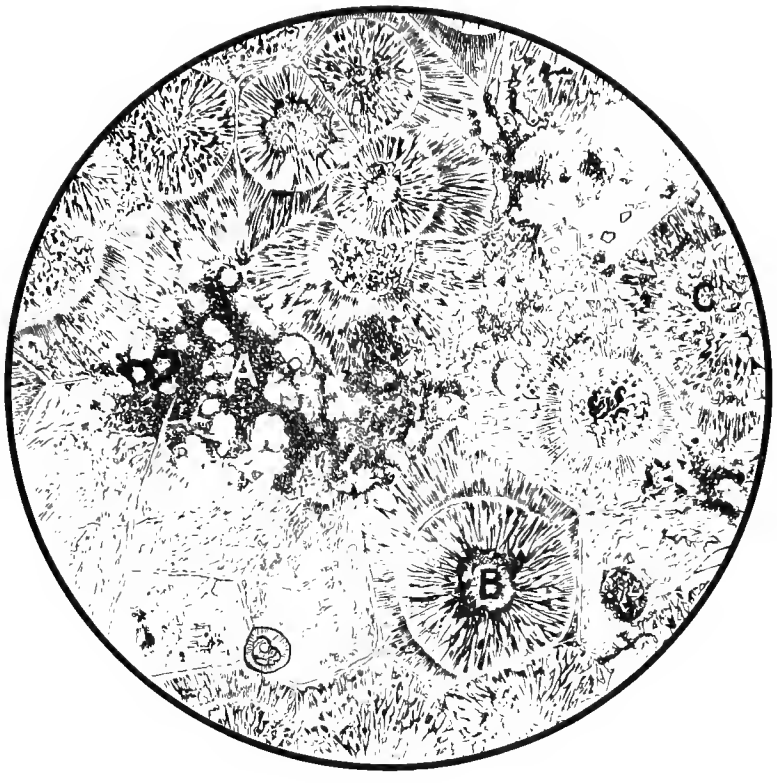
Fig. 1 magnified 50 diameters. Ordinary light.

Fig. 2 magnified 120 diameters. Nicols crossed.

In the upper figure the perlitic structure is clearly shown. A secondary quartz-vein is represented in the left-hand portion of this figure. The perlitic structure proves the rock to have been originally a glass. The appearances represented in the lower figure show that the glass has been devitrified. Two types of devitrification may be recognized (a) the spherulitic and (b) the micro-crystalline. The former is most extensively developed on the left, the latter on the right. The spherulites are positive and give a well-defined black cross. This rock forms a portion of a lava-flow associated with the Coniston limestone (Ordovician). It has been described by Mr. RUTLEY (Q.J.G.S. Vol. XL., 1884, p. 340), who has generously presented the author with the drawings from which this plate has been prepared.

KEY PLATE 39.

FIG 1



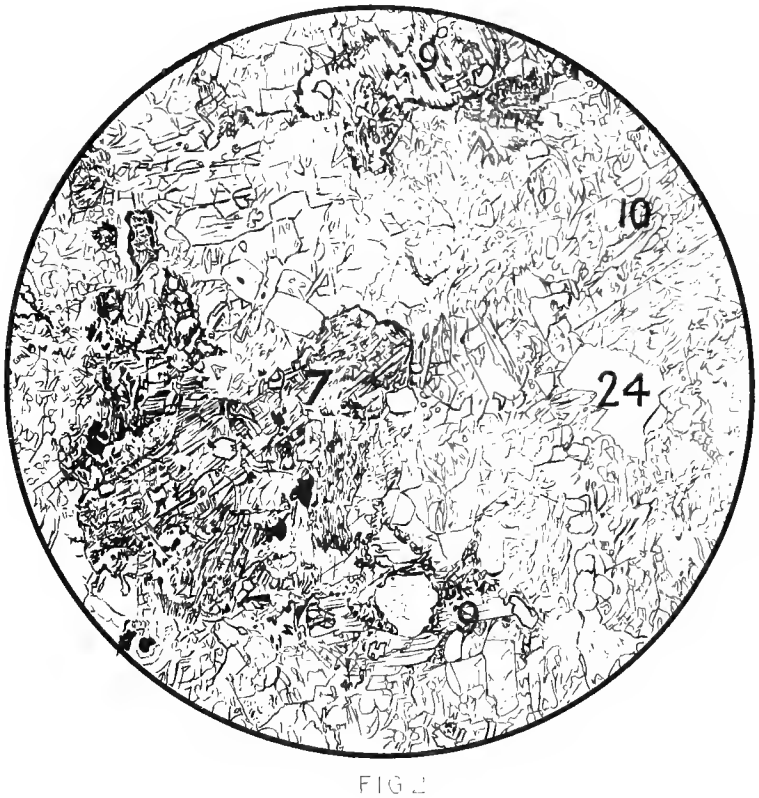


FIG 2

PLATE XXXIX.

FIG. 1.

SPHERULITIC FELSITE

ARRAN.

Magnified 10 diameters. Ordinary light.

In this rock there are no definitely recognizable minerals. The darker portions of the figure are crowded with ill-defined, brownish granules. The lighter portions are crystalline and often give definite extinction over considerable areas. The distribution of the brown granular matter has been determined by the crystallization of the substance which forms the lighter portions.

In the irregular patch (A), somewhat to the left of the centre, there is no radial structure. The lighter spots extinguish as individuals. In the other portions of the figure a radial structure may be seen. This is due to the crowding together of the brown granular matter along certain lines. When the section passes through the centre of a spherulite a nucleus, in which there is no radial structure, is sometimes seen (B) and this nucleus is surrounded by two zones showing radial structure. When the section is not cut through the centre of the spherulite the ends of the radiating bundles are seen. Where several spherulites have been developed in close juxta-position the mass is divided into polygonal spaces.

The radial structure is not so well seen under crossed nicols as it is in ordinary light. The spherulites do not give a black cross, but are composed of irregular crystalline patches which give uniform extinction. (Compare structure developed in glass by devitrification. HERMAN & RUTLEY, Proc. Roy. Soc., 1885, p. 87). This rock has been described by Mr. ALLPORT (G.M., 1872, p. 536), and Professor BONNEY (G.M., 1877, p. 499).

FIG. 2.

AUGITE-GRANITE.

LINHOPE SPOUT, CHEVIOT.

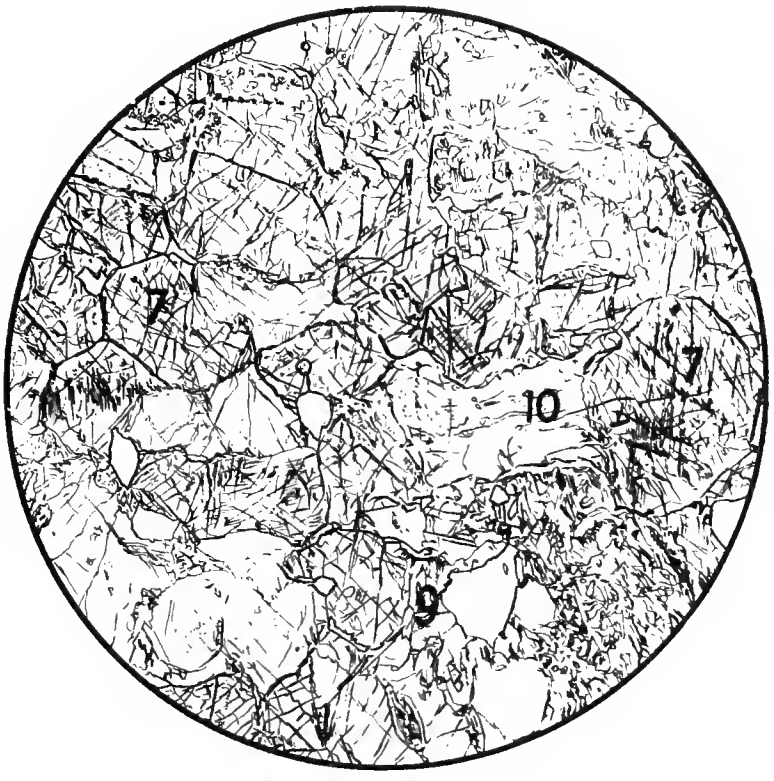
Magnified 25 diameters. Polarizer only.

The minerals represented are augite (7), dark-mica (9), quartz (24), felspar (10) and magnetite.

The augite is pale in colour and belongs to the malacolite variety. The dark-mica is strongly pleochroic. Magnetite occurs as inclusions in the augite and dark-mica. The felspar is partly striated and partly unstriated. In other parts of the same slide the quartz and felspar form micro-pegmatite.

KEY PLATE 40

FIG 1



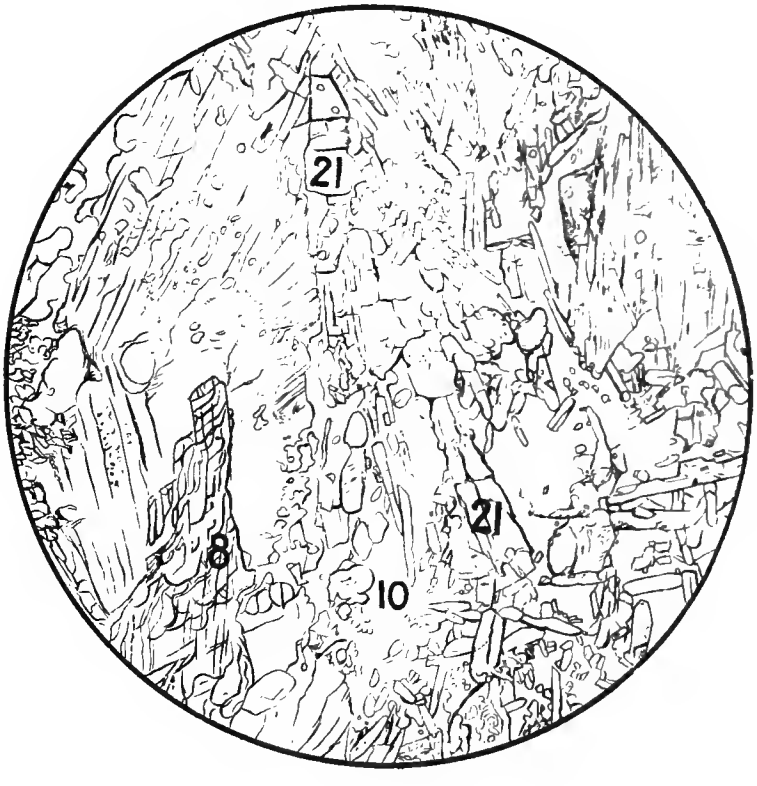


FIG 2.

PLATE XL.

FIG. 1.

FELSPAR-PYROXENE ROCK.

KYLE SKU, SUTHERLAND.

Magnified 30 diameters. Ordinary light.

The minerals represented are felspar (10), pyroxene (7), brown mica (9) and iron-ores.

The felspar occurs in grains of tolerably equal dimensions in the different directions. Fine lamellar twinning is sometimes present, sometimes absent. The monoclinic pyroxene is green in thin section (the tint is slightly exaggerated in the figure). It shows good prismatic cleavages and not unfrequently contains numerous inclusions arranged in one or more sets of parallel planes. In another portion of the same slide hypersthene occurs.

This rock forms a portion of the banded gneissic series of Sutherland and often shows foliation in hand specimens.

FIG 2.

ZOISITE-AMPHIBOLITE.

NEAR BEINN HUTIG, SUTHERLAND.

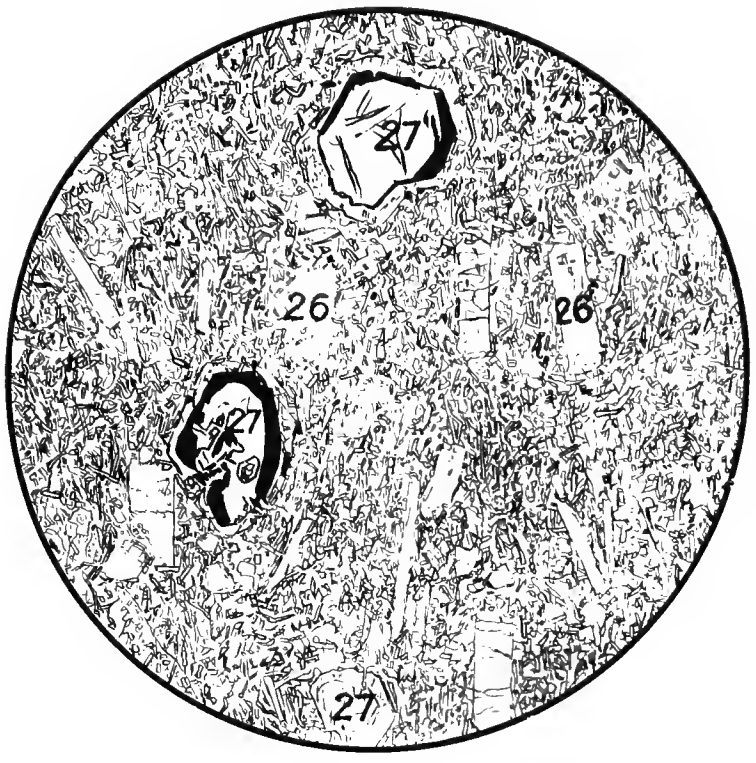
Magnified 50 diameters. Ordinary light.

The minerals represented are hornblende (8), zoisite (21), and felspar (10).

The zoisite-prisms lie in a colourless matrix, the larger grains of which often show the lamination of plagioclase. Some of the colourless material may be quartz. The rock occurs in an area of regional metamorphism. It is probably a metamorphosed basic igneous rock.

KEY PLATE 41.

FIG 1



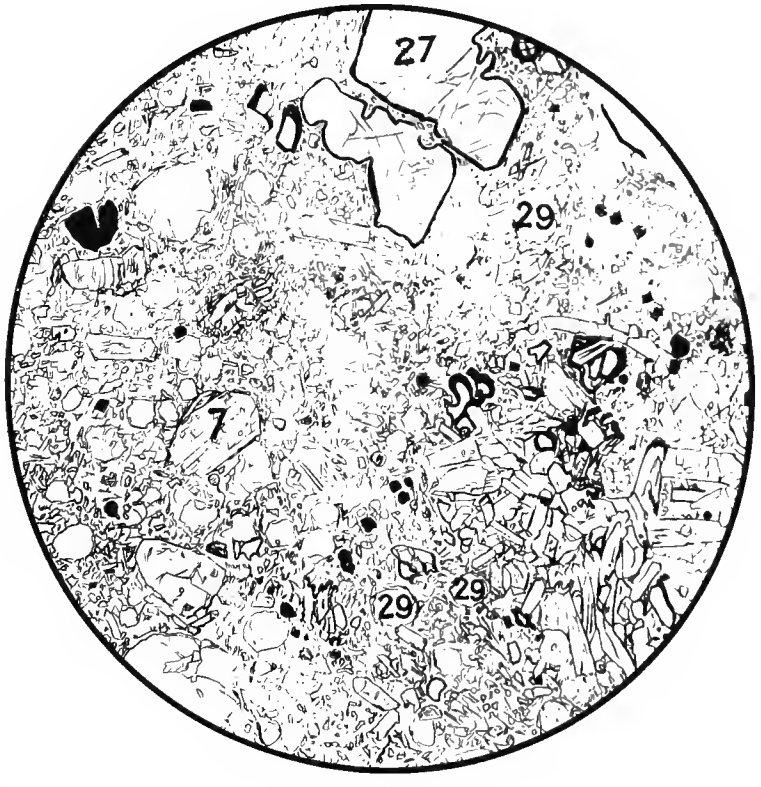


FIG 2

PLATE XLI.

FIG. 1.

PHONOLITE.

WOLF ROCK, CORNWALL.

Magnified 30 diameters. Ordinary light.

The minerals represented are nosean (27), sanidine (26), and ægirine.

The nepheline is present as a constituent of the ground-mass and can, as a rule, only be recognized by the use of a high power and with a careful adjustment of the light. The small green microlites are in most if not in all cases ægirine. This rock was first described by Mr. ALLPORT.

FIG. 2.

LEUCITOPHYRE.

RIEDEN, THE EIFEL.

Magnified 25 diameters. Ordinary light.

The minerals represented are nosean (27), leucite (29), pyroxene (7).

Nepheline is present as a constituent of the groundmass, but is not recognizable in the figure.

This foreign rock is introduced because leucite is an important mineral which has not, as yet, been found in Britain.

KEY PLATE 42.

FIG. 1.

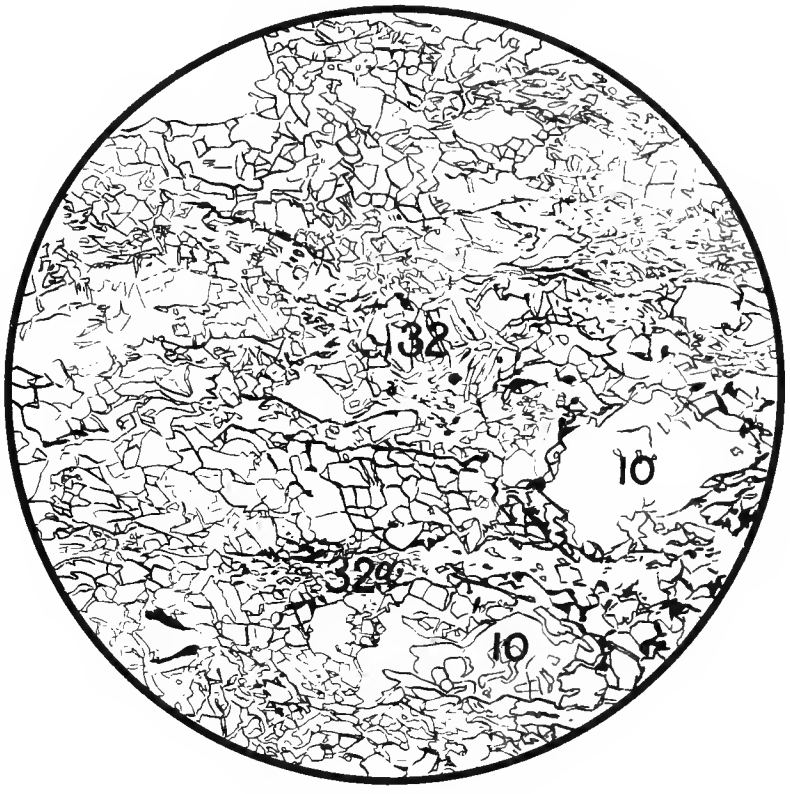


FIG. 2.

PLATE XLII.

FIG. 1.

SCHISTOSE GRANITE.

PORTHALLA.

Magnified 35 diameters. Nicols crossed.

The minerals represented are felspar (10), white or very pale green mica (32) and quartz.

The felspar occurs partly in the form of large irregular grains and partly as a constituent of a micro-crystalline mosaic. When viewed with ordinary light the large grains appear turbid whereas the small grains are water clear. The light-coloured mica also occurs in two forms, as crystalline plates or scales and as a crypto- or micro-crystalline aggregate. The rock is fissile in the mass. In the microscopic slide the planes of schistosity are defined by the distribution of the white mica. They run from left to right in the figure.

For a further description of this rock, see page 319 of the text.

FIG 2.

SCHISTOSE GRANITE.

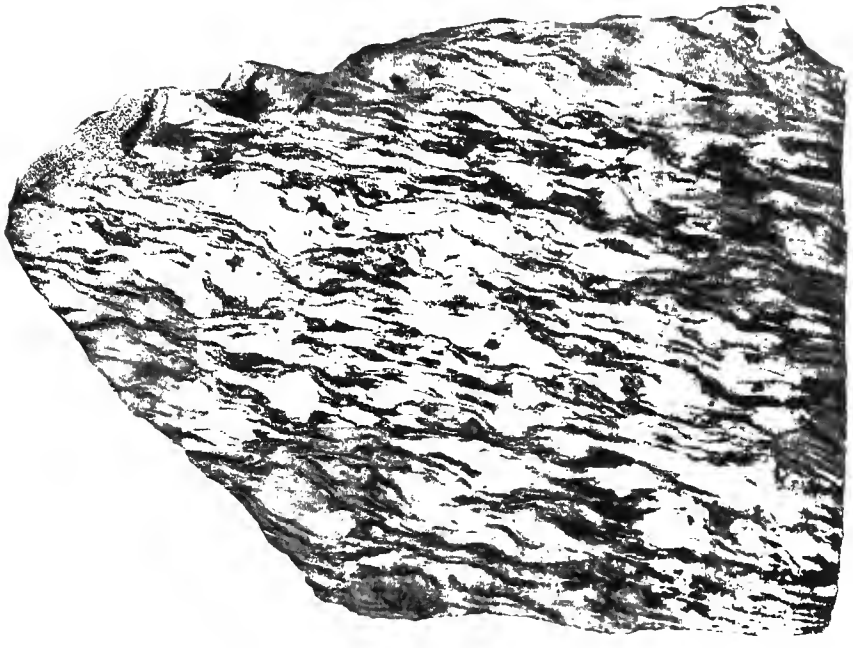
MARGIN OF WICKLOW MASS, NEAR BALLY BRACK STATION.

Magnified 25 diameters. Nicols crossed.

The minerals represented are felspar (10), white mica (32) and quartz. The relations of the constituents are similar to those described above. The portions of the rock in which the parallel structure is most marked are richest in the quartz-felspar mosaic and in the white mica. One of these portions occupies the middle-third of the figure and runs from left to right. This rock contains garnet as an accessory constituent.

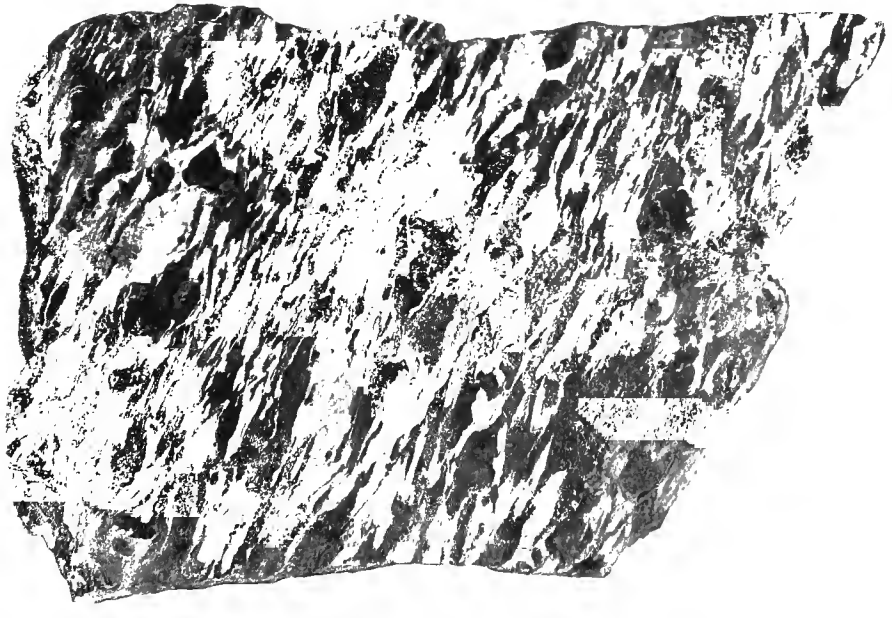
The granite of Wicklow is intrusive in Lower Palæozoic strata. It is, however, of pre-Carboniferous age.

PLATE XLIII.



FOLIATED GRANITE.

BEN VUROCH, PERTHSHIRE.



FOLIATED GABBRO.

KARAKCLEWS, CORNWALL.

PLATE XLIII.

FIG. 1.

FOLIATED GRANITE.

BEN VUROCH.

Polished surface; natural size.

The white lenticles are formed of felspar and quartz. Under the microscope the centre of a lenticle is seen, in most cases, to consist of a large irregular grain of felspar showing microcline structure. The marginal portions of a lenticle are formed of felspar or of felspar and quartz in the granulitic condition. The granulitic aggregate often penetrates, traverses, and more or less replaces the large individuals of felspar (see figs. 22 and 23, p. 175).

The dark bands which sweep round the white lenticles are formed of black and white micas and a granulitic aggregate of quartz and felspar. Garnet is present as an accessory mineral. For a further description of this rock, see page 325.

FIG. 2.

FOLIATED GABBRO.

KARAKCLEWS.

Polished surface. Natural size.

The white patches are formed of alteration products after felspar. The dark coloured knots, lenticles and streaks are composed of diallage and hornblende.

The two figures on this plate illustrate the fact that precisely similar types of foliation occur in rocks of very different chemical and mineralogical compositions.

KEY PLATE. 44.

FIG. 1.

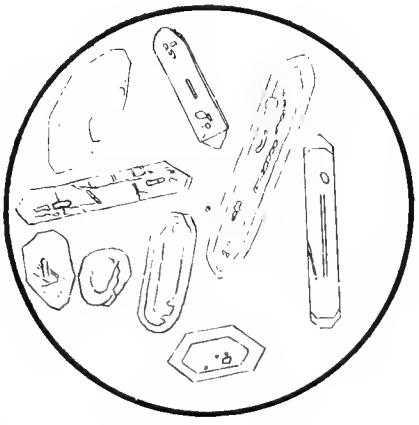


FIG. 2.

FIG 3

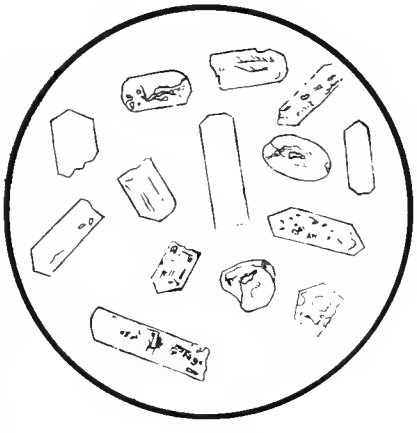


FIG. 4

FIG 5.

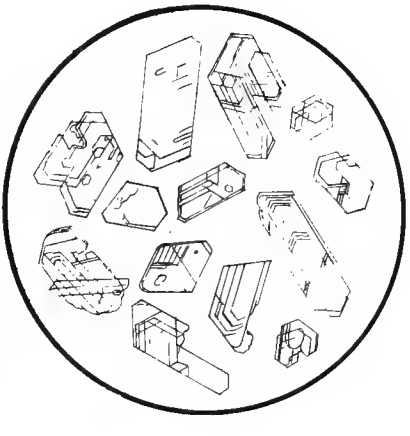


FIG 6.

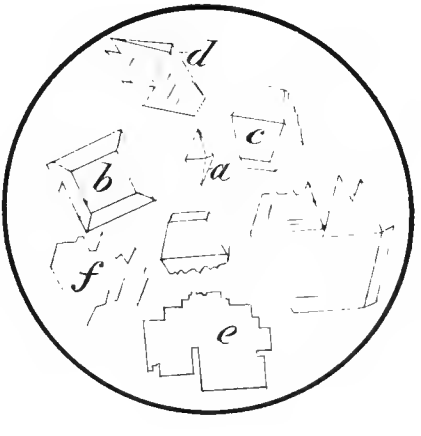


PLATE XLIV.

FIG. 1.

ZIRCON.

BAGSHOT SANDS, HAMPSTEAD HEATH.

Magnified 100 diameters.

FIG. 2.

CYANITE.

BAGSHOT SANDS, HAMPSTEAD HEATH.

Magnified 100 diameters.

This mineral is represented by cleavage flakes. Those flakes which are parallel to the first cleavage (100) give an extinction angle of about 30° (26° to 33°) referred to the trace of the second cleavage (010) and are seen, in convergent polarized light, to be approximately at right angles to a negative bisectrix. Those parallel to the second cleavage give an extinction of only 3° or 4° referred to the trace of the first cleavage. The rectangular form of many of the flakes is due to a separation parallel to 001.

FIG. 3.

TOURMALINE.

BAGSHOT SANDS, HAMPSTEAD HEATH.

Magnified 100 diameters. Drawn with polarizer only; short axis right and left.

FIG. 4.

RUTILE.

BAGSHOT SANDS, HAMPSTEAD HEATH.

Magnified 100 diameters.

A, *b* and *c* represent characteristic twins of rutile. The mineralogical composition of the sands of Hampstead Heath has been described by Mr. DICK (*Nature*, Vol. XXXVI., p. 91), and figures 1, 2, 3 and 4 are drawn from his preparations.

FIG. 5.

KAOLINITE.

AMLWCH, ANGLESEA.

Magnified 50 diameters.

This mineral was analysed by Mr. TOOKEY (see Dr. PERCY on Fuel, &c., 1875, p. 93) SiO_2, 46·53; Al_2O_3, 38·93; H_2O (by diff.), 14·54.

FIG. 6.

ANATASE.

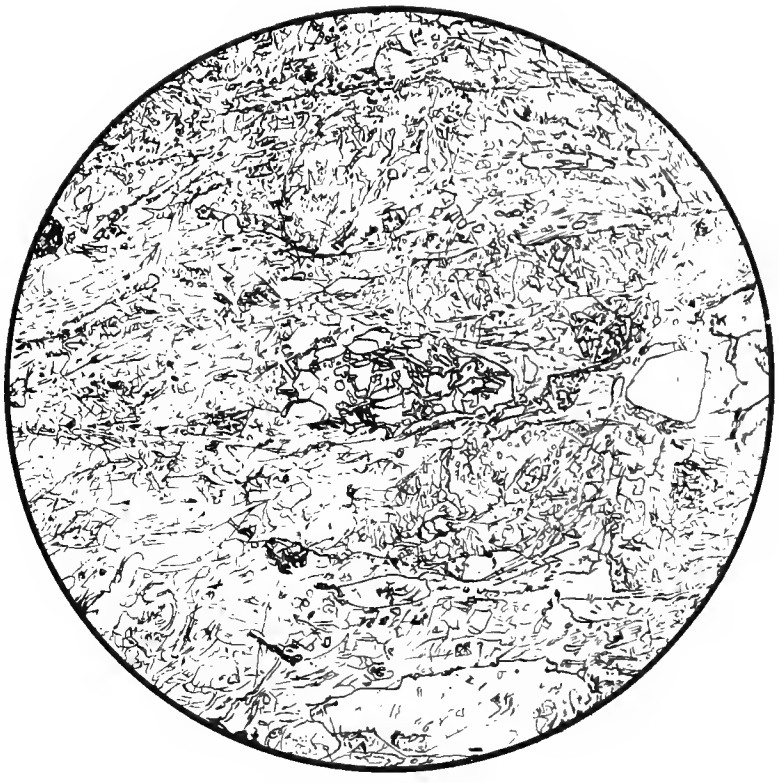
CLEVELAND IRONSTONE.

Magnified 80 diameters.

The forms only of the crystals are represented. The larger crystals are opaque except at the edges. *A* is a crystal showing only the form (111); *b* and *c* are combinations of the forms (111) and (001); *d* shows the characteristic striation due to the oscillatory combination of (111) and (001). *E* and *f* are merely the outlines of two aggregates.

KEY PLATE 45.

FIG. 1.



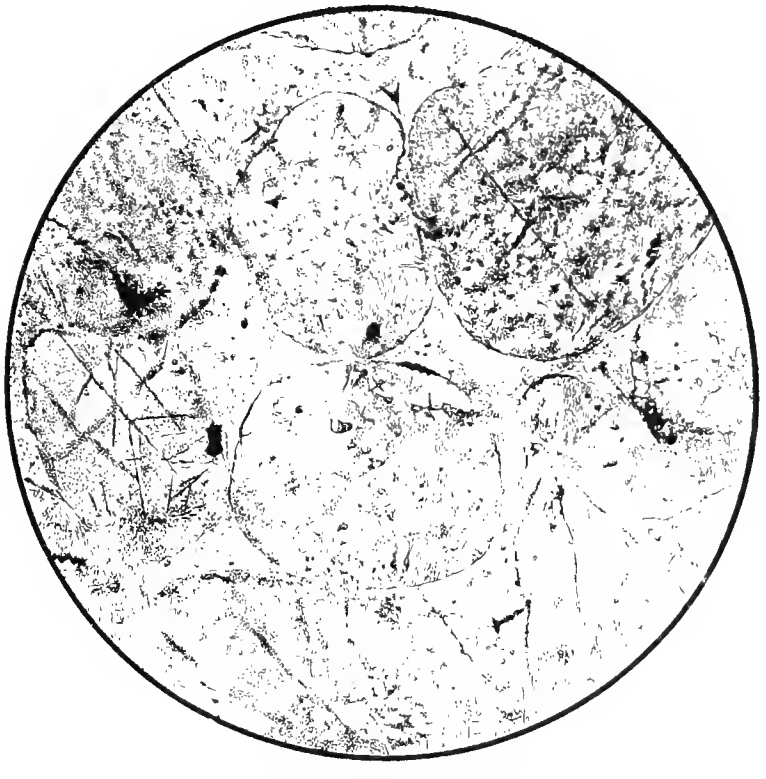


FIG 2

PLATE XLV.

FIG. 1.

SCHISTOSE VOLCANIC BRECCIA.

LLYN PADARN, N. WALES.

Magnified 30 diameters. Ordinary light.

The central portion of the figure is occupied by a vesicular lapillum, rendered almost opaque by finely disseminated magnetite. It contains some small felspars. This lapillum was evidently produced by the explosion of a highly basic lava. The ferro-magnesian constituents of the original breccia or tuff are now represented by chloritic or serpentinous minerals associated with calcite. The fine grey matrix in which the volcanic fragments lie may represent ordinary sediment. A quartz-grain is seen to the right of the centre.

The rock has been described by Prof. GREEN (Q.J.G.S., Vol. XLI., p. 77). It is either of Cambrian or pre-Cambrian age.

FIG 2.

QUARTZITE.

THE LICKEY HILLS.

Magnified 55 diameters. Ordinary light.

This Figure must be examined in connection with Fig. 1, Plate XLVI. The original grains of quartz are seen to have been well-rounded, probably by sub-aerial attrition. The interspaces between the original grains are occupied by secondary quartz which is somewhat freer from inclusions than the original grains.

KEY PLATE 46.

FIG I

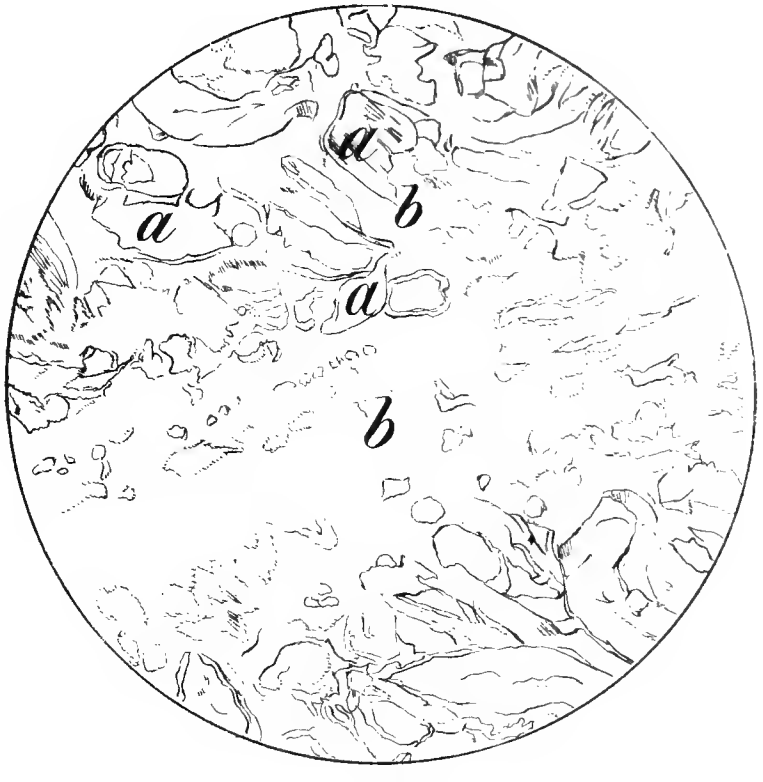


FIG.2.

PLATE XLVI.

FIG. 1.

QUARTZITE.

LICKEY.

Magnified 55 diameters. Nicols crossed.

This represents fig. 2, Plate XLVI., under crossed nicols. The secondary quartz (A) is seen to split up into distinct portions which are in optical continuity with the adjacent grains (B and C). The individual grains are sometimes uniform in their optic properties (C) and sometimes consist of two or more distinct portions (B and D).

FIG. 2.

SCHISTOSE QUARTZITE.

ERRIBOL, SUTHERLAND.

Magnified 25 diameters. Nicols crossed.

This figure is an attempt to represent the appearance of a quartzite which has been affected by dynamic metamorphism.

The relics of the original grains (A) give undulose extinction and lie in a crypto-crystalline aggregate (B), apparently formed by the crushing of the original constituents. Planes of schistosity in the rock are seen, under the microscope, to correspond to bands entirely composed of the crypto-crystalline material. One such band traverses the figure from left to right. These bands represent the extreme of mechanical metamorphism so far as the quartzite is concerned.

This figure must not be looked at too closely. A fine diagonal striation which is not visible in the section has been represented as crossing the central band of crypto-crystalline material.

The rock from which the section has been prepared was collected by the author under Prof. LAPWORTH'S guidance in the summer of 1883.

KEY PLATE 47.

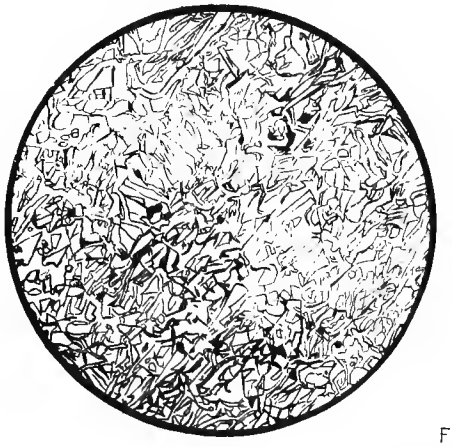


FIG.4.

FIG.1.

FIG 5

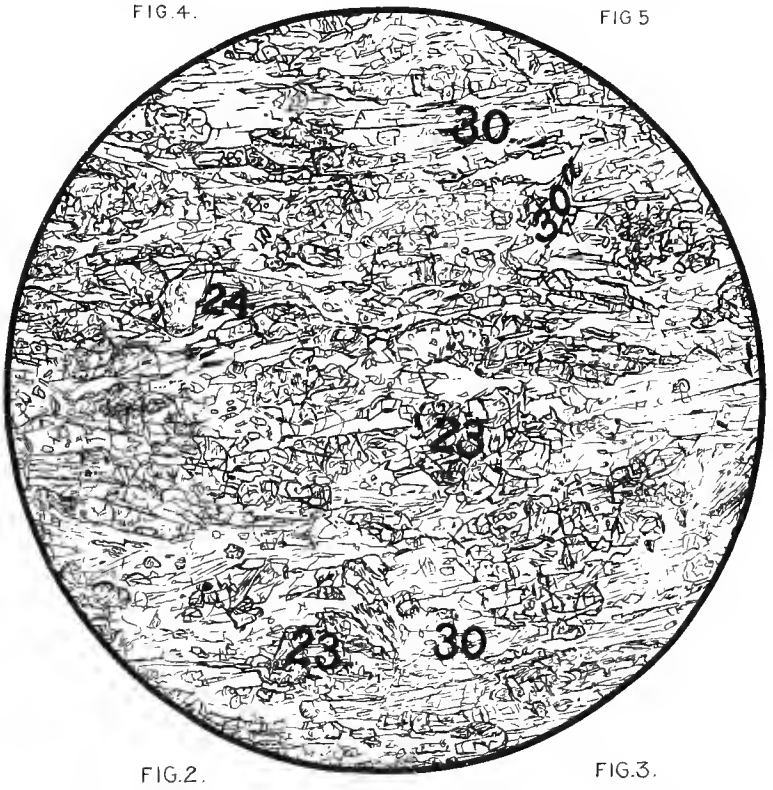
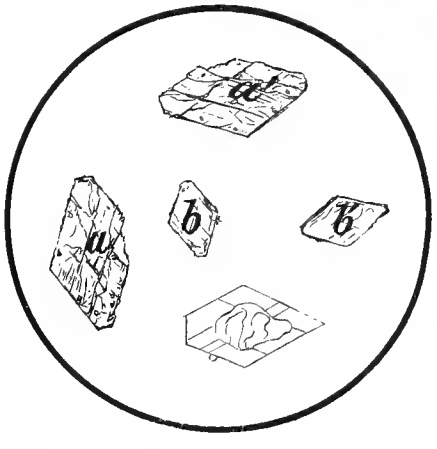


FIG.2.

FIG.3.



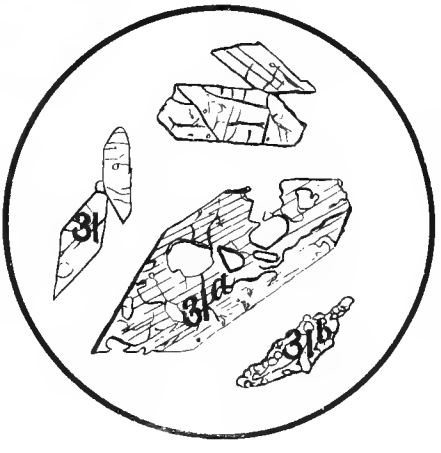


PLATE XLVII.

FIG. 1.

GLAUCOPHANE-EPIDOTE-SCHIST.

ANGLESEA MONUMENT.

Magnified 80 diameters. Polarizer only; short axis right and left.

The minerals represented are glaucophane (30), epidote (23), quartz (24), and iron-ores.

The individual crystals of glaucophane are elongated in the direction of their vertical axes, and they are so arranged in the rock that their longest axes are, in most cases, approximately parallel to each other. The figure represents the slide as it appears when viewed with rays vibrating parallel to the direction in which the longest axes (corresponding to the axes of least elasticity) of most of the individuals lie. The dominant colour of the glaucophane is that characteristic of rays vibrating parallel to γ. One individual (30a) cuts the schistosity obliquely and gives indications of the violet tint characteristic of rays vibrating parallel to β.

The epidote occurs for the most part in grains, which, however, frequently show a tendency to elongation in the direction of the orthodiagonal.

In other portions of the same slide quartz is more abundant than in the part represented in the figure. It occurs in granular aggregates which are penetrated by idiomorphic glaucophane.

In addition to the minerals mentioned above the rock contains a white mica and minute vividly polarizing grains of a biaxial mineral possessing a very high refractive index (sphene).

FIG. 2.

GLAUCOPHANE.

Magnified 200 diameters. Polarizer only; short axis right and left.

This figure represents cross-sections of glaucophane from the same rock. *A* and *a*' represent the same individual. As the a and β axes lie approximately in the plane of the cross-section, this figure represents the colours characteristic of rays vibrating parallel to these axes. Combining this figure with Fig. 1, we have the complete scheme of pleochroism:—a, pale yellow; β, violet; γ, blue. The cross-sections are bounded by the prismatic faces (110) with indications of the clino-pinacoid (010).

FIG. 3.

SPHENE.

Magnified 50 diameters. Ordinary light.

This figure represents sections of sphene occuring in the mica-diorite of Pen Voose (see Fig. 1, Plate XXXII.). The colourless inclusions in 31a are composed of felspar. 31b represents a kernel of iron ore zoned by sphene.

FIG. 4.

NOSEAN.

Magnified 60 diameters. Ordinary light.

This figure represents a very thin section of the phonolite of the Wolf rock (see Fig. 1, Plate XLI.). The distribution and arrangement of inclusions in the nosean may be clearly recognized. The ground-mass is formed of ægirine and nepheline. The small nepheline crystals show indications of crystalline outline.

FIG. 5.

MICROPEGMATITE.

Magnified 50 diameters. Nicols crossed.

This represents the micropegmatite which plays the rôle of ground-mass in the quartz-gabbro (augite-diorite) of Carrock Fell.

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